ORIGINAL ARTICLES

MEASUREMENT OF PEDIATRIC ILLNESS SEVERITY USING SIMPLE PRETRANSPORT VARIABLES

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ABSTRACT

Objective. To test the hypothesis that pretransport variables can predict in-hospital mortality that will correlate with major interventions and unplanned events during interfacility transport. **Methods.** A cohort of children (*n* = 2,253) transported by a specialized pediatric team to a children's hospital were studied. At the time of referral, data collected included age (months), heart rate, systolic blood pressure, respiratory rate, retractions, stridor or wheezing, seizures, skin perfusion, oxygen requirement, and mental status. Using univariate and stepwise logistic regression, variables predictive of in-hospital mortality were selected from a training set (*n* = 1,111) and assigned integers based on their computed coefficients. Probability of in-hospital mortality was calculated using the total integer score and age. The risk of mortality derived from the training set was validated in the remaining patients (*n* = 1,142) by comparing the observed and predicted mortalities. Major interventions performed and unplanned events were determined for each of five predetermined mortality risk groups. **Results.** Variables (integers) predicting in-hospital mortality included systolic blood pressure (11), respiratory rate (6), oxygen requirement (11), and altered mental status (11). Observed mortality was similar to predicted mortality in all risk categories for the validation sample. As risk of mortality increased, so did the performance of major interventions and the occurrence of unplanned events. **Conclusion.** Four pretransport variables predicted in-hospital mortality. Risk of mortality correlated with the incidence of major patient interventions, and the occurrence of unplanned events increased as well. This model might be useful in comparing different transport systems using severity-adjusted assessment of children requiring interfacility transport. **Key words:** severity of illness index; transportation of patients; pediatric.

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Critically ill infants and children often require transfer from a local general community hospital to a regional or tertiary care center. A variety of modes for interfacility transport of critically ill infants and children are currently in operation. These include private automobile, local emergency medical services (EMS) where training and equipment are highly variable, hospital-based or privately-owned critical care transport teams, and dedicated specialized pediatric or neonatal critical care transport teams. The latter are usually based at a pediatric critical care center and are staffed with any combination of nurse practitioners, nurses, respiratory therapists, paramedics, and physicians, all of whom have considerable experience and training in the care of critically ill infants and children.

Many factors influence the choice of transport mode and type of transport team. Weather conditions, geography, distance, and stabilization capabilities of the referring hospital vary among states and regions. There are currently no standard criteria for choosing the appropriate mode or team to transport a critically ill infant or child. In this era of managed care and cost containment, the benefit of a pediatric specialized transport service is being questioned and is yet to be determined. While a few regional studies have suggested that pediatric specialized services might reduce morbidity,[1–3] valid comparisons between different types of transport systems have not been done, because there is no objective clinical tool upon which

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TABLE 1. Physiologic Variables

Variable	Abnormal Range
Heart rate (beats/min)	
Age <1 month	<80 and >180
Age 1–12 months	<80 and >160
Age 13 months–5 years	<75 and >160
Age >5 years	<70 and >110
Systolic blood pressure (mm Hg)	
Age <1 month	<60
Age 1–12 months	<70
Age 13 months–5 years	<75
Age >5 years	<85
Respiratory rate (breaths/min)	
Age <1 month	<25 and >45
Age 1–12 months	<25 and >40
Age 13 months–5 years	<20 and >35
Age >5 years	<15 and >25
Chest wall retractions	
Stridor or wheezing	
Seizures	
Skin perfusion	Pale, cold, cyanotic, capillary refill >3 seconds
Oxygen requirement*	Cyanosis improved by delivery of oxygen or SaO_2 <0.90 at any time
Altered mental status†	Obtundation: difficult to arouse, no spontaneous eye opening, inappropriate verbal response, not obeying commands, unequal or nonreactive pupils

*Does not include patients with congenital cyanotic heart disease or patients with fixed intracardiac/intrapulmonary shunts.

†The majority of the referring institutions were unfamiliar with the Glasgow Coma Score and its components, rendering it an inconsistent tool for scoring in the pretransport arena.

everyone can agree for measuring severity of illness in the transport environment. Investigators have tried to use risk-of-mortality scores designed for pediatric intensive care populations with variable success in transport populations.[1,4–7]

When determining severity of illness in the transport environment, the tool used for its measurement should be simple and readily available to the caregiver. In this study, we hypothesized that simple pretransport variables could accurately predict in-hospital mortality, and that risk of mortality would correlate with the number of major patient interventions performed and the incidence of unplanned events that occur during the transport process.

METHODS

Patients

Since this study did not involve patient risk, the institutional review board waived the need for consent. This was a cohort study of consecutive children (n = 2,253) transported to Children's Hospital of Pittsburgh by a specialized pediatric interfacility transport team from July 1993 through May 1996. One thousand one hundred twenty-one patients were transported by ground, 1,007 by rotor wing, and 124 by fixed wing. All interfacility transport requests were directed to an intensive care unit (ICU) physician (ICU attending or fellow) through a central communications specialist. On completion of the consultation with the referring physician, the ICU physician chose the appropriate transport team. The transport team consisted of a dedicated critical care transport nurse, a physician (third-year pediatric resident or ICU fellow), and, on occasion, a respiratory therapist.

On arrival at the referring hospital, the transport team assessed the patient and performed any necessary therapeutic interventions to stabilize the patient for safe and effective transport. The transporting physician reported back to an ICU physician at Children's Hospital and a decision was made as to the most appropriate admission area for the patient, according to the clinical assessment of the ICU physician.

Relevant patient data collected upon referral included the patient's age in months, and nine physiologic variables (Table 1). For patients referred from an emergency department (ED), the data reflected those obtained from the time of arrival to the ED until the time of request for transport. For inpatients, the data reflected those obtained in the previous 24 hours or from the time of admission until the time of request for transport if the patient was hospitalized for less than 24 hours. Variables were scored if they were abnormal at any time during these time periods. Variables and their ranges were determined by a group of pediatric intensivists who actively participated in pediatric interfacility transport. The basis for variable selection by unanimous consensus was that patients who demonstrated derangement in respiratory, cardiac, or central nervous systems at the time of referral could likely require life-sustaining interventions or result in significant morbidity or mortality during transport. The criteria for the selection of these variables were that they could be easily measured in a brief period of time by referring physicians and that they could be obtained consistently on every transport. Major interventions performed by the referring hospital and the transport team were recorded and included fluid resuscitation of more than 20 mL/kg for hypotension or shock, cardiopulmonary resuscitation (CPR) medications and/or use of pressor agents, endotracheal intubation, osmotic agents, or barbiturates used in treating increases in intracranial pressure, and anticonvulsants for active seizures. Unplanned events that occurred while the patient was under the care of the transport team were also recorded. These included death or CPR en route, hypotension, airway mishaps, aspiration, hypoxia, pneumothorax, loss of essential vascular access, hypothermia, and equipment malfunction resulting in patient deterioration. Diagnostic categories, length of stay, and in-hospital deaths were recorded for each patient at the completion of hospitalization.

Prehospital and trauma transports were excluded from this study because the transport team did not participate in these referrals.

Model Development

The database was divided into a training set (n = 1,111) and a validation set (n = 1,142). The training set was used to develop a model of variables that would predict in-hospital mortality. Construct validity of the predictor was demonstrated by applying it to a more severely ill population group—the overall mortality rate in our transport population being 7.8%. First, a univariate analysis (chi-square) was performed on all physiologic variables recorded at the time of the referral, with the outcome variable being in-hospital mortality. Variables that were not significantly associated with death ($p > 0.25$) were eliminated from the model. The remaining variables were entered into a stepwise logistic regression analysis to eliminate those with a low predictive significance for in-hospital mortality ($p \geq 0.05$). The regression coefficients of the variables selected to be used in the model were multiplied by 10 so that an integer value could be assigned. The integer values were added to determine a composite score for each patient. A final logistic regression analysis was performed with the composite score and age (months) with the outcome variable being in-hospital mortality. The prediction of in-hospital mortality for each patient was calculated as follows:

$$r = a \bullet \Sigma \text{ integers of predictive variables} + b \bullet \text{age (months)} + c$$

where a and b are the logistic regression coefficients for the sum of the integers of the predictive variables and age respectively, and c is the intercept. Probability of in-hospital mortality is then expressed as:

$$\Pr(\text{death}) = e^r/(1 + e^r)$$

An independent sample (n = 1,142) from the patient database was used for model validation. The probability of in-hospital mortality was calculated for each patient in the validation set using the equation constructed from the training sample. Patients were classified into five arbitrary mortality risk groups chosen *a priori*. Observed mortality was compared with expected mortality using Flora's method of z scores.[8] Major interventions that were performed by the referring hospital and the transport team, and the occurrence of at least one unplanned event during the transport process, were described for each of the mortality risk groups. Demographic data are described using mean and standard deviation. Probability estimates for in-hospital mortality are described as percentages with 95% confidence intervals.

Table 2. Diagnostic Categories for the 2,253 Patients Transported

Diagnostic Category	Number (%)
Cardiac	144 (6.4%)
Respiratory	1,097 (48.7%)
Sepsis, septic shock	275 (12.2%)
Neurologic	491 (21.8%)
Ingestion	86 (3.8%)
Gastrointestinal (bleeding, hepatic failure)	160 (7.1%)

Table 3. Univariate (Chi-square) Analysis of the Nine Pretransport Variables for Prediction of In-hospital Mortality

Pretransport Variable	p-value
Heart rate	0.4379
Systolic blood pressure	0.0000
Respiratory rate	0.0004
Chest wall retractions	0.6816
Seizures	0.7688
Stridor or wheezing	0.7919
Abnormal skin perfusion	0.0000
Oxygen requirement	0.0000
Altered mental status	0.0000

Table 4. Stepwise Logistic Regression for Remaining Variables from Univariate Analysis Significantly Associated with In-hospital Mortality

Pretransport Variable	Coefficient Estimate	Score
Systolic blood pressure	1.1120	11
Respiratory rate	0.6372	6
Oxygen requirement	1.0845	11
Altered mental status	1.0747	11
Abnormal skin perfusion	Not significant	N/A

Results

Two thousand two hundred fifty-three patients were transported to Children's Hospital for a variety of diagnostic categories (Table 2) during the study period. One thousand two hundred sixteen (54%) and 1,037 (46%) patients were transported from EDs and inpatient units, respectively. The mean and standard deviation for age, hospital days, and ICU days were 30.8 ± 49.3 months, 11.3 ± 18.1 days, and 3.6 ± 11.5 days, respectively. One hundred seventy-eight (7.8%) children died in the hospital.

The training set contained 1,111 patients and included 88 deaths. Based on the univariate analysis (Table 3) heart rate, retractions, stridor or wheezing, and active seizures were eliminated from further analysis. Stepwise logistic regression analysis of the five remaining variables (Table 4) eliminated abnormal skin perfusion, leaving systolic blood pressure, respi-

TABLE 5. Mortality Risk Model from Training Sample Using Physiologic Variables Associated with Death

Variables* Present	Probability of Death (%)	95% Confidence Interval
None	1.26	0.60, 1.92
BP	3.74	2.62, 4.86
RR	2.36	1.46, 3.26
AL	3.61	2.51, 4.71
OX	3.64	2.53, 4.75
BP, RR	6.85	5.36, 8.34
BP, AL	10.23	8.45, 12.01
BP, OX	10.32	8.53, 12.11
RR, AL	6.62	5.16, 8.08
RR, OX	6.68	5.21, 8.15
AL, OX	9.98	8.22, 11.74
BP, RR, AL	17.74	15.50, 19.98
BP, RR,OX	17.88	15.63, 20.13
BP, AL, OX	25.22	22.67, 27.77
RR, AL, OX	17.34	15.12, 19.56
All variables present	38.94	36.07, 41.81

*BP = hypotension; RR = abnormal respiratory rate; AL = altered mental status; OX = oxygen requirement. Parameters for these physiologic variables are defined in Table 1.

TABLE 6. Predicted versus Observed Mortality in the Validation Sample for Different Mortality Risk Categories

	Risk Categories for Prediction of In-hospital Mortality				
	<1%	1–9%	10–19%	20–29%	≥30%
n	39	914	169	8	12
Predicted	0.32	38.7	25.4	2.2	4.6
Observed	1	49	31	3	6
p-value	0.23	0.09	0.23	0.50	0.42

ratory rate, oxygen requirement, and altered mental status as variables that were significantly associated with death ($p < 0.05$). There were no interactions found between the remaining variables. Integers based on the computed coefficients for each of the variables were: systolic blood pressure (11 points), respiratory rate (6 points), oxygen requirement (11 points), and altered mental status (11 points). The final logistic regression associating these four physiologic parameters and age with in-hospital mortality, resulted in the following equation:

$$r = 0.100 \bullet \Sigma \text{ integers} - 0.004 \bullet \text{age (months)} - 4.253$$

A model using all possible combinations of the predictive variables and their probability estimates from the training sample is shown in Table 5, and demonstrates that mortality risk increases with increasing physiologic derangement.

The validation set contained 1,142 patients and included 90 deaths. Predicted and observed mortality rates are shown for each of the mortality risk groups in Table 6. Observed mortality was similar to predicted mortality in all risk categories.

Three hundred seventy nine (33%) patients required major interventions at the referring hospital, and 296 (26%) patients required additional interventions by the transport team (Table 7). Unplanned events occurred in 70 (6.1%) patients during the time the patient was with the transport team (Table 8). The association of mortality risk with the performance of at least one major intervention by the referring hospital and the transport team, and the occurrence of at least one unplanned event, is shown in Figure 1. As the risk of mortality increased, so did the performance of major interventions and the occurrence of unplanned events. Moreover, when a major intervention had already been performed by the referring institution at the time of the referral call, the patient was likely to require a major intervention by the transport team during the transport process 61.5% of the time (CI 56.2–66.3%).

DISCUSSION

Along with the regionalization of pediatric emergency and critical care centers has come the growth of interfacility transport programs, allowing tertiary medical care to be expanded geographically. Critically ill infants and children are often taken to the nearest local ED by the EMS provider or by their parents, where their conditions are assessed to determine the extent of their illnesses or injuries in order to provide initial stabilization. Many community hospitals do not have the personnel, space, or facilities to provide critical care to infants or children beyond the period of initial stabilization. Therefore, transfer of these children to pediatric critical care centers becomes necessary. The goal of an interfacility transport service should be to provide care commensurate with the degree of illness severity in a safe and effective manner, thereby minimizing the risk of deterioration and unplanned events before and during the en route phase of transport. There is little information available to guide the referring physician in choosing the most appropriate team composition and mode of transport. Currently, these decisions depend on a number of factors that include distance, weather, air or surface transport availability, team experience and training, equipment needs, severity of illness, and expense.

TABLE 7. Major Interventions Performed by the Referring Hospital and the Transport Team (*N* = 1,142 Patients)

	Referring Hospital (*n* = 379; 33%)	Transport Team (*n* = 296; 26%)
Fluids >20 mL/kg for hypotension or shock	64	123
Cardiopulmonary resuscitation medications/pressors	89	98
Intubation	308	86
Management of intracranial pressure	9	14
Anticonvulsants for active seizures	154	74

Despite the large number of children and the costs associated with transport, little has been done to measure the quality of transport services, particularly with regard to patient outcomes.

Defining the appropriate outcome variable for use in transport can be difficult as well as controversial. Many "intuitive" outcome measures may ultimately provide data useful only to a local region, or they may prove to be statistically significant but not clinically useful. For example, using patient deterioration during transport as an outcome variable might depend on stabilization before transport, experience of the transport team, progression of the child's underlying illness, and the total time required for transport. The use of procedural events or major interventions during transport as an indicator of patient severity also has its limitations.[9] For example, endotracheal intubation might be performed because of the patient's clinical condition, team protocol, or a caregiver's decision to "protect" the patient's airway for fear of respiratory deterioration, or because transport time is lengthy. Intensive care unit admission may appear to be a useful outcome variable, because if that level of care is needed at the pediatric critical care center, it may also be needed en route. However, pediatric ICUs may have different criteria for admission, and centers with intermediate, observational, or stepdown units may avoid ICU admission for patients who would have to go to an ICU at another institution. Therefore, patient deterioration during transport, requirement for major interventions, ICU admission, and even length of ICU stay as outcome variables could reflect regional practices and not necessarily patient severity.

TABLE 8. Unplanned Events While the Patient Was with the Transport Team (*N* = 1,142 Patients)

Unplanned Event	Occurrences
Death en route	1
Cardiopulmonary resuscitation en route	1
Hypotension upon arrival at receiving hospital*	7
Dislodged or malpositioned endotracheal tube	3
Plugged endotracheal tube	1
Airway not clear upon arrival at receiving hospital†	14
Pulmonary aspiration	1
SaO_2 <90% or documented central cyanosis for >5 minutes‡	13
Pneumothorax	1
Loss of nasogastric tube or essential IV§	8
Hypothermia (<35°C) upon arrival	3
Equipment malfunction¶	20

*Hypotension defined by the parameters in Table 1.

†Patient requiring bag-valve-mask ventilation and endotracheal intubation upon arrival.

‡Did not include patients with fixed pulmonary or cardiac shunts.

§Nasogastric tube in patients with bowel obstruction and/or requiring mechanical ventilation; loss of essential IV being used for inotropic and/or pressor support.

¶Equipment malfunction that resulted in patient deterioration.

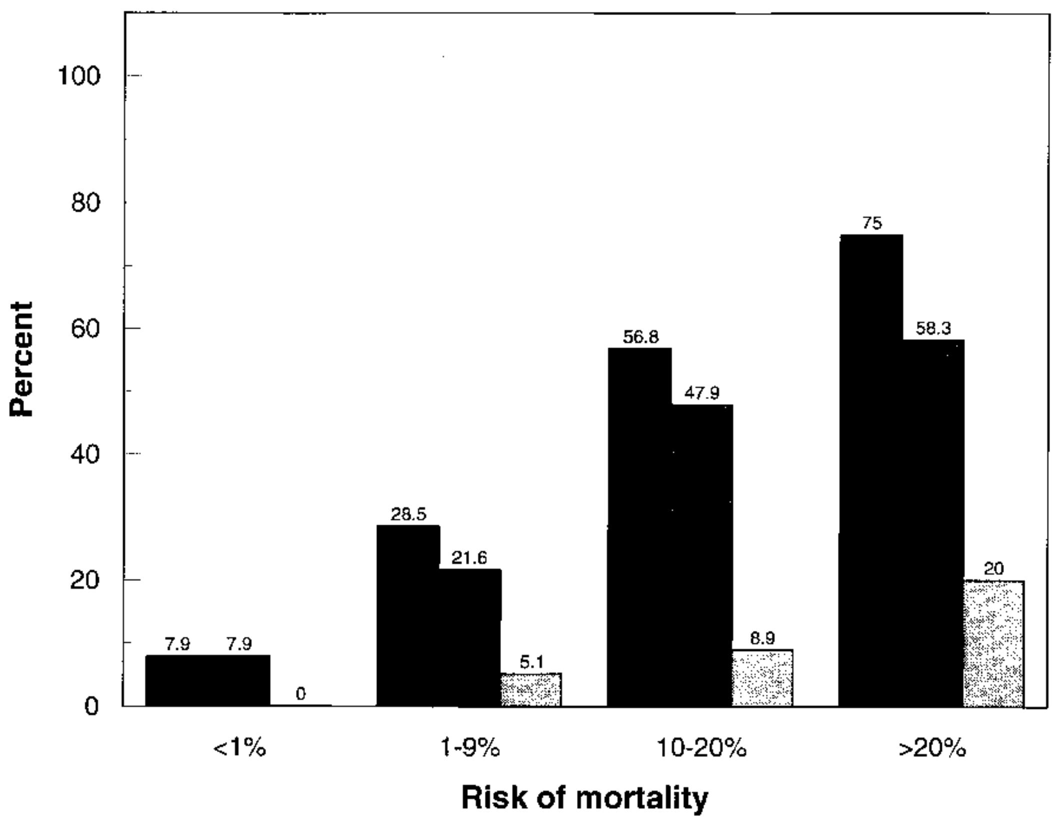

FIGURE 1. Incidence of major interventions by referring hospital (*black bars*), transport team (*light gray bars*), and unplanned events during transport process (*dark gray bars*) as they relate to pretransport risk of mortality.

The Pediatric Trauma Score and the TRISS methodology have been used to measure outcome and quality of care at trauma centers, but offer nothing for critically ill children who are not injured.[10,11] Previous studies have used the Pediatric Risk of Mortality (PRISM) score[12] to measure transport severity of illness, with varying degrees of success.[1,4–7] The PRISM score, a measure of severity of illness and validated only in pediatric ICU (PICU) settings, is a logistic function estimating PICU mortality risk from the patient's age, operative status, and scores on 14 routinely measured physiologic variables in a PICU setting.[12] Kanter et al.[4] found that a pre-ICU PRISM score as a measure of illness severity provided an estimate of the probability of in-hospital mortality. However, the pre-ICU PRISM consistently underestimated in-hospital mortality in the authors' transport population.[4] This might be explained from our findings in a previous study where a median of only three of the 14 variables used in calculating PRISM were available for scoring in the pretransport setting.[5] The PRISM score retains the philosophy that only those variables that caregivers believe are necessary to be measured should be measured.[12] This should never be assumed in the transport arena, where pediatric assessment skill is highly variable and likely to result in over- or underestimation of patient severity.[5]

In this study, we substantiated our hypothesis that four simple pretransport variables can reasonably predict in-hospital mortality in a population whose diagnostic categories were similar to those previously reported.[13–17] Although in-hospital mortality as an outcome variable is not always related to what has occurred during transport, it is an endpoint that is objective, clearly defined, measurable, and constant over time. Lacking a "gold standard" for describing severity of illness in patients being transported to a tertiary pediatric center, the physiologic variables and their ranges in this study were chosen arbitrarily by a panel of pediatric intensivists who are actively involved as command physicians in pediatric transport. These variables and their ranges were chosen by consensus to reflect the physiologic derangement that is seen commonly in the pediatric transport population and likely to result in a request for transfer to a tertiary pediatric center. We also found that each of these variables was obtained easily and consistently on every transport. Breathing rate, and not signs of increased work of breathing (retractions, stridor, wheezing), was the only respiratory system parameter that significantly predicted death. Heart rate and systolic blood pressure ranges were consistent with those found in other studies.[18,19] Importantly, heart rate never proved to be a significant predictor of death in our population, further corroborating the teaching in Pediatric Advanced Life Support that tachycardia can be a nonspecific sign of distress.[20] While abnormal skin perfusion was independently associated with death in the univariate analysis, it became nonsignificant in the multivariate analysis. We speculate that abnormal skin perfusion, while an important early sign of shock, is unlikely to be associated with mortality when the systolic blood pressure remains within normal ranges for age and the patient is being treated appropriately. In our patient population, no deaths occurred in children who had abnormal skin perfusion and a normal systolic blood pressure for age. We also found that within the confines of our definition of altered mental status, any degree of patient obtundation was predictive of in-hospital mortality. While the Glasgow Coma Scale[21] might have been a more objective tool for measuring central nervous system derangement, we found that referring physicians were often unfamiliar with the use of this scale, thereby making it an inconsistent tool for patient assessment at the time of referral. Laboratory data and working diagnosis, while important, were intentionally left out of the model since they are often unavailable or inaccurate in the transport setting, potentially leading to over- or underestimation of outcome. Having a probability of in-hospital mortality of only 38.9% when all variables were present is probably true for several reasons. First, these variables were scored at the time of referral and could have been corrected by either the referring physician and/or the transport team. Second, in-hospital death could have been the result of other variables not measured in this study such as suboptimal stabilization before and during transport, multisystem organ dysfunction, disease process, and complications during the hospitalization that were not related to transport.

Our secondary hypothesis has far more important implications for transport. This study showed that as risk of mortality increased, so did the incidence of referring hospital and transport team interventions as well as transport team unplanned events. These issues are fundamental in choosing the appropriate transport team and mode of transportation. If an infant or child were at risk of needing a major intervention or having an unplanned event because of being more severely ill, the referring physician might consider choosing a team that is more experienced and adept at treating pediatric emergencies, or perhaps choose a more rapid means of transportation. Another important finding of the study was that 61.5% of children who already had a major intervention performed at the referring facility had an additional major intervention performed by the transport team. This finding was also confirmed by previous studies.[9,13] At times, caregivers from referring institutions in our region have questioned the utility of sending a highly skilled transport team for a patient "already packaged to go," implying that additional procedures or problems were unlikely.

This study is the first attempt in developing a benchmarking process for pediatric transport that did not use a previously validated scoring system for PICU evaluation. Variables used in this study as predictors of outcome were consistently available and easy to obtain in the transport arena. If this model proves to be valid in other regions, it might be useful as a simple method of classifying children when making comparisons between different types of transport systems. For example, do pediatric specialized care transport systems improve outcome (morbidity and mortality) of children when compared with other teams who transport children? Individual transport teams could be compared and studied for factors associated with quality, e.g., education and experience in caring for critically ill children, so that systemwide improvements can be made.

This study has a number of limitations. First, in-hospital mortality is not necessarily related to what occurs on transport, but to a number of factors, including severity of illness, disease process and in-hospital complications. One might consider studying only those patients who died within the first 24–48 hours following the acute illness, which might correlate better to transport issues. However, there would have been very small patient numbers, and because of advancement of PICU technology (e.g., ECMO), patients who historically would have died sooner during their illness are now surviving for longer periods during their hospitalization. Second, pretransport risk of mortality does not necessarily prescribe what needs to be done during the transport. Therefore, this model should not be applied to individual patients for the purpose of triage or decision making during the transport process. Third, this study is limited by the development and validation of a model from a single, tertiary pediatric center that used pediatric specialty care teams exclusively for interfacility transport and, therefore, should be considered preliminary. It has not been evaluated in the prehospital setting or for victims of trauma. Fourth, calibration of this model might have been improved by using laboratory values and perhaps even diagnosis in the logistic model. However, this might also add complexity and variables to the model that might not always be available in the transport setting.

CONCLUSION

This study substantiated our hypothesis that simple pretransport variables can reasonably predict in-hospital mortality. Moreover, the study has shown that as risk of mortality based on pretransport variables increases, so does the incidence of major patient interventions performed by the referring hospital and transport team and also the occurrence of unplanned events during transport. Validation of this model in a multicenter fashion will enable severity-adjusted assessment of children requiring transport and might prove to be useful in making comparisons between different transport systems.

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