Incidence and predictors of critical events during urgent air–medical transport

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ABSTRACT

Background: Little is known about the risks of urgent air–medical transport used in regionalized health care systems. We sought to determine the incidence of in-transit critical events and identify factors associated with these events.

Methods: We conducted a population-based, retrospective cohort study using clinical and administrative data. We included all adults undergoing urgent air–medical transport in the Canadian province of Ontario between Jan. 1, 2004, and May 31, 2006. The primary outcome was in-transit critical events, which we defined as death, major resuscitative procedure, hemodynamic deterioration, or inadvertent extubation or respiratory arrest.

Results: We identified 19 228 patients who underwent air–medical transport during the study period. In-transit critical events were observed in 5.1% of all transports, for a rate of 1 event per 12.6 hours of transit time. Events consisted primarily of new hypotension or airway management procedures. Independent predictors of critical events included female sex (adjusted odds ratio [OR] 1.3, 95% confidence interval [CI] 1.1–1.5), assisted ventilation before transport (adjusted OR 3.0, 95% CI 2.3–3.7), hemodynamic instability before transport (adjusted OR 3.2, 95% CI 2.5–4.1), transport in a fixed-wing aircraft (adjusted OR 1.5, 95% CI 1.2–1.8), increased duration of transport (adjusted OR 1.02 per 10-minute increment, 95% CI 1.01–1.03), on-scene calls (adjusted OR 1.7, 95% CI 1.4–2.1) and type of crew (adjusted OR 0.6 for advanced care paramedics v. critical care paramedics, 95% CI 0.5–0.7).

Interpretation: Critical events occurred in about 1 in every 20 air–medical transports and were associated with multiple risk factors at the patient, transport and system levels. These findings have implications for the refinement of training of paramedic transport crews and processes for triage and transport.

Air–medical transport is critical in regionalized health care systems to ensure access to distant specialized health care resources. Transport of acutely ill patients removes them from the hospital setting and may put them at risk for clinical deterioration. Although little is known about the risk of adverse clinical outcomes associated with transport, patients may deteriorate in transit because of progression of underlying diseases, the physical stress of transport, or care delivered before or during transport.

The reporting of adverse events and outcomes during transport is inconsistent, and reproducible predictors of in-transit adverse events have not been identified.[1–3] Skilled transport teams may avert clinical deterioration and adverse events through timely critical interventions; therefore, measurement of both clinical deterioration and resuscitative interventions (critical events) is important.[4,5] Characterization of critical events could be used to reduce medical errors, improve processes related to equipment and transport, and optimize the triage and preparation of patients before transport and the matching of transport crews and resources to patients at highest risk.

Our goal was to determine the incidence of in-transit critical events during urgent air–medical transport and identify factors independently associated with these events.

Methods

Study design

We conducted a population-based retrospective cohort study using data from the provincial air–medical transport organization (Ornge) of Ontario. Ontario is Canada's second largest province, with a landmass of more than 1 million km^2. Northern Ontario constitutes 87% of the land area of the province, although it contains less than 7% of the population. Ornge

conducts more than 17 000 air–medical transports annually using rotary-wing (helicopter) and fixed-wing aircraft with specially trained paramedic flight crews under the direction of a central transport medicine physician. Clinical data are recorded in-flight by transport crews, transcribed by data abstractors and validated by range and logic checks.

We included all air–medical transports of patients 18 years of age or older in the province of Ontario between Jan. 1, 2004, and May 31, 2006. We excluded nonurgent transports of patients to a convalescent facility or home, scheduled transports for medical appointments, treatments or repatriation and transports related to organ donation. We also excluded from the main analysis patients who were transported by primary care paramedic crews, because these crews are generally assigned low-risk patients and have a limited scope of resuscitative interventions (Appendix 1, available at www.cmaj.ca/cgi/content/full/cmaj.080886/DC1).

The research protocol for our study was approved by the Sunnybrook Health Sciences Centre Research Ethics Board.

Data collection

We obtained data on the clinical and demographic characteristics of patients. We ascertained the administration of assisted ventilation, including manual ventilation with a bag-valve-mask, from mechanical ventilation records. We defined baseline hemodynamic instability as a systolic blood pressure of less than 80 mm Hg or a mean arterial pressure of less than 60 mm Hg before departure from the sending site, or the administration of vasopressors before departure from the sending site. We assigned each transport to 1 of 7 diagnostic categories (respiratory, cardiovascular, trauma, neurologic, surgical, obstetrics and other medical diagnoses) based on coding of the primary diagnosis by the paramedic crew.

We also obtained transport-specific characteristics. We imputed the distance of straight-line transport from the postal codes of the sending and receiving institutions[6,7] or from the transponder data of global-positioning-system units when available. We also used postal codes to determine the rural or urban status of the sending site using Statistics Canada Census indicators.[8] To account for differences in population density, geography and medical resources, we classified origin of transport as either northern Ontario (rural and remote) or southern Ontario (more urban and dense) based on administrative boundaries (Local Health Integration Networks 13 and 14 of the Ontario Ministry of Health and Long-Term Care). We defined an on-scene call as a transport in which crews delivered acute care or resuscitation on arrival at a site outside a health care facility.

Outcome measures

The primary outcome was in-transit critical events, which we defined as death, major resuscitative procedures (Box 1), hemodynamic deterioration (systolic blood pressure < 80 mm Hg, mean arterial pressure < 60 mm Hg or in-flight administration of a vasopressor), inadvertent extubation, or respiratory arrest. The event must have occurred between the time of departure from the sending facility and the time of arrival at the receiving facility. We selected the composite

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Box 1: List of major resuscitative procedures included in the primary outcome of in-transit critical events

Airway procedure
- Needle thoracostomy
- Needle or surgical cricothyroidotomy
- Nasotracheal intubation
- Orotracheal intubation
- Removal of foreign object
- Other Advanced Life Support airway
- Laryngeal mask airway
- Ascherman chest seal

Cardiac procedure
- Cardiopulmonary resuscitation or chest compressions
- Cardioversion
- Carotid sinus massage
- Precordial thump
- Manual defibrillation
- Automatic defibrillation
- Transcutaneous pacing
- Administration of dextrose or glucagon

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outcome to represent a fatal or life-threatening clinical deterioration. We also recorded the number of discrete critical events involving the same patient during a single transport.

Statistical analysis

We generated descriptive statistics with planned secondary analyses stratified according to sex, diagnostic category, type of sending site (e.g., acute care hospital) and geography. We assessed variables for collinearity. We used multivariable logistic regression to identify factors that were independently associated with in-transit critical events. We decided that age and sex had sufficient importance to include them in the multivariable model. We selected all other candidate variables for multivariable analysis using a threshold for inclusion of $p < 0.25$ from a χ^2 test or univariable logistic regression as appropriate.[9,10] We handled missing data by list-wise deletion, whereby we excluded the entire record from analysis if any single value was missing. We excluded variables that were missing more than 20% of observations. We included data from low-risk transports by primary care paramedics in a sensitivity analysis to assess their impact on our principal findings. We used the Kruskal–Wallis test for medians and χ^2 test for binary and categorical variables for comparisons across groups.

Results

We identified 49 986 transports of patients during the study period. We excluded 30 758 (9173 transports of pediatric or neonatal patients, 10 644 low-risk transports, 3256 land-based transports and 7685 transports by primary care paramedic crews), for a final cohort of 19 228 urgent air–medical transports. Characteristics of patients and transports are shown in Table 1. Details of the cohort stratified by sex and diagnostic

category are provided in Appendices 2 and 3 (available at www.cmaj.ca/cgi/content/full/cmaj.080886/DC1). Patient characteristics and case mix varied according to transport origin (data not shown); 64.4% of all transports originated in northern Ontario. Compared with those of southern origin, northern transports had significantly more surgical (12.4% v. 5.4%; $p < 0.001$) and medical (19.1% v. 11.6%; $p < 0.001$) diagnoses and fewer instances of baseline hemodynamic instability or assisted ventilation before transport (5.4% v. 22.7%; $p < 0.001$). They were also significantly longer (median 266 km v. 98 km; $p < 0.001$) and involved more frequent use of fixed-wing aircraft (64.0% v. 8.0% in southern Ontario; $p < 0.001$). The majority of on-scene calls were by helicopter (91.8%). Nearly all on-scene calls in southern Ontario were related to trauma, whereas those in northern Ontario reflected a broader range of diagnoses.

Outcomes

At least 1 critical event occurred during 981 (5.1%) of the transports. Compared with patients who had no critical events, those who did were older (median age 58 [interquartile range 37–78] v. 53 [interquartile range 35–68]; $p < 0.001$), had greater baseline hemodynamic instability (16.9% v. 2.8%; $p < 0.001$) and were more likely to have received assisted ventilation before transport (27.1% v. 9.1%; $p < 0.001$). In-transit hemodynamic deterioration was the most frequent critical event (3.2%, $n = 613$), followed by major resuscitative procedure (2.1%, $n = 413$). New vasopressor medications were administered during 155 transports (0.8%). Twelve deaths occurred during transport (0.1%). The use of resuscitative procedures was commonly related to airway management (Table 2). The success rate for first-attempt intubation was 64.5% for oral intubations and 75.0% for nasal. Unintentional extubation was infrequent ($n = 5$). Among transports in which resuscitative procedures were administered, 290 (70.2%) had only 1 resuscitative procedure and 27 (6.5%) had 4 or more. We observed a total of 1435 discrete critical events, for a rate of 1 event per 12.6 hours of transport time.

The characteristics of critical events varied by diagnostic category and sex. The rate of critical events was significantly lower (2.5%) among obstetric patients. Female and male patients had similar crude rates of in-transit critical events (5.3% and 4.9%; $p = 0.19$). Women had a significantly higher rate of in-transit hemodynamic deterioration (3.8% v. 2.7%; $p < 0.001$) and lower rates of resuscitative procedures (1.8% v. 2.5%; $p < 0.001$) compared with men. Rates of critical events were lower among transports of northern origin (4.5% v. 5.7% for those of southern origin; $p < 0.001$) and transports from nonacute care facilities (3.9% v. 5.1% for acute care facilities and 6.7% for on-scene calls; $p < 0.001$).

Factors associated with critical events

We selected 13 variables for multivariable analysis (Appendix 4, available at www.cmaj.ca/cgi/content/full/cmaj.080886/DC1). We excluded rural status and transport distance because more than 20% of the data for these variables was missing. The final model consisted of 13 389 transports, of which 832 had in-transit critical events. Multiple

Table 1: Baseline characteristics of 19 228 patients who underwent urgent air–medical transport in Ontario between Jan. 1, 2004, and May 31, 2006

Characteristic	No. (%) of patients*
Patient	
Age, median (IQR)	53.0 (35–68)
Sex	n = 18 866
Female	8 609 (45.6)
Male	10 257 (54.4)
Diagnostic category	n = 18 001
Airway or respiratory disease	1 294 (7.2)
Cardiovascular	5 937 (33.0)
Neurologic	2 496 (13.9)
Trauma	1 741 (9.7)
Obstetric	1 302 (7.2)
Surgical	1 806 (10.0)
Other medical	3 425 (19.0)
	n = 19 228
Hemodynamic instability at baseline	673 (3.5)
Assisted ventilation before transport	1 923 (10.0)
Transport	
Distance, km, median (IQR)	214 (109–346)
Duration, min, median (IQR)	59.0 (36–85)
Time on ground with patient, min, median (IQR)	17.0 (10–32)
Type of aircraft	n = 17 819
Fixed-wing	7 128 (40.0)
Helicopter	10 691 (60.0)
Type of paramedic crew	n = 19 228
Advanced care	8 460 (44.0)
Critical care	10 768 (56.0)
Contextual	
Sending facility	n = 17 868
Acute care hospital	12 549 (70.2)
Non-acute care facility	2 638 (14.8)
On-scene call	2 681 (15.0)
Location of sending site	n = 15 363
Rural	8 573 (55.8)
Northern Ontario†	9 894 (64.4)
Time of transport	n = 19 228
Night	7 499 (39.0)
Weekend	5 768 (30.0)
Season	n = 19 228
Spring	4 383 (22.8)
Summer	5 268 (27.4)
Autumn	5 101 (26.5)
Winter	4 476 (23.3)

Note: IQR = interquartile range.
*Unless stated otherwise.
†Local Health Integration Networks 13 or 14 as defined by the Ontario Ministry of Health and Long-Term Care.

patient- and transport-level factors were independently associated with in-transit critical events (Table 3). Female sex (adjusted odds ratio [OR] 1.3, 95% confidence interval [CI] 1.1–1.5), administration of assisted ventilation before transport (adjusted OR 3.0, 95% CI 2.3–3.7) and baseline hemodynamic instability (adjusted OR 3.2, 95% CI 2.5–4.1) were all significantly and independently associated with in-transit critical events. Transport in a fixed-wing aircraft (adjusted OR 1.5, 95% CI 1.2–1.8), duration of transport (adjusted OR 1.02 per additional 10 minutes, 95% CI 1.01–1.03), on-scene calls (adjusted OR 1.7, 95% CI 1.4–2.1) and type of crew (adjusted OR 0.6 for advanced care paramedics v. critical care paramedics, 95% CI 0.5–0.7) were also associated with in-transit critical events.

Sensitivity analysis

In a prespecified sensitivity analysis, we included transports by primary care paramedic crews, increasing the cohort to 26 913 transports. Critical events occurred during 4.1% of transports, for a rate of 1 event per 24 hours of transport time. In multivariable analysis, the results were similar to those of the main model with the exception of an association between age of patient and the outcome (OR 1.005, 95% CI 1.001–1.010). Transports by primary care paramedics were much more frequent in northern Ontario (37.9% v. 12.9% of transports in southern Ontario); also, they had low rates of in-transit critical events (1.7%) and administration of resuscitative procedures (0.3%).

Table 2: Major resuscitative procedures that occurred during the air–medical transports

Procedure	No. (%) of observed procedures* n = 751
Airway*	
Oral endotracheal intubation†	197 (26.2)
Other advanced life support	101 (13.4)
Needle thoracostomy	63 (8.4)
Nasal endotracheal intubation†	28 (3.7)
Ascherman chest seal	19 (2.5)
Laryngeal mask	5 (0.7)
Cricothyroidotomy	2 (0.3)
Cardiac	
Cardiopulmonary resuscitation or chest compressions	98 (13.0)
Administration of dextrose or glucagon	95 (12.6)
Transcutaneous pacing	63 (8.4)
Manual defibrillation	50 (6.7)
Automatic defibrillation	13 (1.7)
Cardioversion	12 (1.6)
Carotid sinus massage	5 (0.7)

*Multiple resuscitative procedures may have been observed in a single transport.
†Includes unsuccessful attempts at intubation.

We conducted 2 post hoc analyses. We stratified data by transport distance (< 125 km, 125–250 km and > 250 km) and found that transports of less than 125 km had more patients who had baseline hemodynamic instability or required assisted ventilation before transport (particularly in trauma and helicopter transports) and more in-transit critical events (5.8% v. 4.7% of transports of 125–250 km and 4.8% of transports of > 250 km). The independent association between fixed-wing transports and critical events was reversed in the short-distance group (OR 0.48 for 125 km transports v. 1.56 for transports of 125–250 km and 1.16 for transports of > 250 km). We also reran our analyses to include terms for distance and interaction between distance and aircraft type; the results were not significant.

Interpretation

We found that an in-transit critical event occurred in 1 in every 20 urgent air–medical transports of adult patients in a transport system covering a large geographic area. This rate is low but clinically important given the serious nature of these events and the challenging out-of-hospital environment in which they occurred. In-transit critical events were independently associated with female sex, use of mechanical ventilation or hemodynamic instability before transport, transport in a fixed-wing aircraft, duration of transport, on-scene calls and type of crew.

The incidence of critical events found in our study cannot be compared directly with rates reported in the literature, given the heterogeneity in the criteria for inclusion, reporting of data and definitions of outcomes in other studies.[3,11–15] The rate we observed is similar to that reported in a study of out-of-hospital transport by fixed-wing aircraft with comparably defined outcomes[12] and higher than the rate in a smaller series from a single-centre organization.[16] The rate of 1 critical event per 12.6 hours of transit time in our study is comparable to rates in other acute care fields of medicine.[4,17–19] Critical events comprised mainly hemodynamic deterioration and administration of major resuscitative procedures during transport. Procedures for airway management were frequently administered, and the rate of successful intubation we observed is consistent with rates reported in other studies.[20–24]

We identified several patient- and transport-level factors that were independently associated with in-transit critical events. Female sex was a significant factor even after adjustment for patient- and transport-level confounders. This association persisted in the sensitivity analysis that included transports with primary care paramedic crews. Evidence is growing that disparities exist between men and women in treatment, utilization of health care resources and outcomes across a wide range of diseases.[25–30] In our study, this observation may be attributable to differences between men and women in how diseases present, how they are treated and patterns of referral and transport-related requests. Systemic biases during assignment of transports could lead to delayed transport of women, with resulting physiologic instability and a higher risk of critical events. Alternatively, the criteria used to triage patients may underestimate the risk of deterioration among female patients. We observed that men were more often transported

by critical care paramedic crews even though their unadjusted rate of in-transit critical events was not significantly different from that of women. Although conclusions about appropriate matching of patients to resources cannot be drawn, better understanding of the root causes of this observation may help optimize allocation of transport resources according to levels of acuity and transport risk of patients.

Although some critical events are likely unpredictable (e.g., unanticipated sudden cardiac arrest), many of the critical events we observed were related to airway management. Some of these events might have been prevented with better elective airway management before transport. In our study, elective intubation of a patient before transport was not a standardized or protocol-driven decision. Further study of this issue could inform policy development and crew training.

Our data suggest that patients who have hemodyamic instability before transport should be given special consideration for pre-emptive airway management, given the strong association with in-transit critical events in this group.

Use of fixed-wing aircraft was associated with in-transit critical events. We hypothesize that this association was attributable to preferential assignment of these aircraft to patients in remote areas and to residual confounding in this patient population rather than to characteristics of the aircraft itself. Supporting this hypothesis was the reversal of this association in short-distance transports in the sensitivity analysis, in which sicker patients with high-risk injuries were more often transported by helicopter. We also observed a 2% increase in the odds of critical events with every 10-minute increase in duration of transport, which would be expected with increasing flight times.

The association between higher levels of paramedic skill and higher rates of critical events was likely related to the assignment of patients who were at highest risk of deterioration to more advanced crews. The scope of practice of advanced care paramedics is similar to that of critical care paramedics, and we rarely observed the few procedures carried out uniquely by critical care paramedics (e.g., needle cricothyroidotomy constituted 0.3% of all observed procedures; $n = 2$). The low rate of critical events among primary care transports may be related to the assignment of crew to low-risk patients or to ascertainment bias. The limited scope of practice of these basic paramedics censored them from many procedures included in our outcome measure.

Issues specific to jurisdiction and context are notable in our study. The geography of Ontario requires longer air–medical transports than those typically reported in the United States[31] or Europe.[32,33] In isolated areas, the levels of skill and training of paramedic transport crews may exceed that of the available local health providers. Thus, crews may deliver primary care and resuscitation "on scene" when picking up a patient. Requests for transport are almost never declined by Ornge because of acuity of illness; when indicated, even patients with the most unstable conditions are transported with aggressive resuscitation before and during transport.

Strengths and limitations
Our study has several strengths. It was population-based and involved the largest published cohort of transported patients. The procedures and clinical protocols used by Ornge Transport Medicine are

Table 3: Factors associated with in-transit critical events in multivariable logistic regression model

Factor	Odds ratio (95% confidence interval)	
	Crude	Adjusted*
Patient		
Age (per 10-year increment)	1.1 (1.0–1.1)	1.0 (1.0–1.1)
Sex, female	1.1 (1.0–1.2)	1.3 (1.1–1.5)
Diagnostic category		
Medical (reference)	1.0	1.0
Surgical	1.1 (0.8–1.4)	1.1 (0.9–1.5)
Respiratory	1.6 (1.2–2.1)	1.0 (0.8–1.4)
Cardiovascular	1.4 (1.2–1.7)	1.3 (1.0–1.6)
Neurologic	1.1 (0.8–1.4)	0.8 (0.6–1.1)
Obstetric	0.6 (0.4–0.8)	0.7 (0.4–1.0)
Trauma	1.4 (1.1–1.7)	1.2 (0.9–1.6)
Hemodynamic instability before transport	3.7 (3.2–4.3)	3.2 (2.5–4.1)
Assisted ventilation before transport	6.5 (5.3–7.9)	3.0 (2.3–3.7)
Transport		
Duration (per 10-minute increment)	1.02 (1.01–1.03)	1.02 (1.01–1.03)
Time on ground with patient, min, median (IQR)	1.06 (1.04–1.07)	1.02 (1.00–1.04)
Fixed-wing aircraft (v. helicopter)	0.8 (0.7–1.0)	1.5 (1.2–1.8)
Advanced care crew (v. critical care crew)	0.5 (0.5–0.6)	0.6 (0.5–0.7)
Contextual		
Sending facility		
Acute care hospital (reference)	1.0	1.0
Non-acute care facility	0.7 (0.6–0.9)	1.1 (0.9–1.4)
On-scene call	1.3 (1.1–1.6)	1.7 (1.4–2.1)
Season		
Winter (reference)	1.0	1.0
Spring	1.1 (0.9–1.3)	1.2 (1.0–1.4)
Summer	1.0 (0.8–1.2)	1.0 (0.8–1.2)
Autumn	0.9 (0.7–1.1)	0.9 (0.7–1.1)

*Adjusted for age, sex, diagnostic category, presence of hemodynamic instability before transport, use of assisted ventilation before transport, duration of transport (in minutes), time on ground with patient before transport, type of aircraft, type of paramedic crew, type of sending facility and season.

similar to those of providers in other jurisdictions, enhancing the generalizability of our findings.

Our study was limited by the use of retrospective data. We were unable to obtain a patient-level score of severity of illness that would allow direct comparison of the incidence of critical events in our study to those reported for other acutely ill populations. Hemodynamic instability and need for assisted ventilation before transport provide only crude surrogate measures for severity of illness. We excluded almost one-quarter of the transports in the data set to limit the cohort to patients who were at highest risk of in-transit clinical deterioration. This large proportion of low-acuity transports is primarily related to a greater need for transport among patients in isolated communities to provide basic care and consultation. Indeed, none of the 10 644 patients designated as low risk had baseline hemodynamic instability or were receiving assisted ventilation before transport; only 1.8% experienced an in-transit critical event, and no deaths occurred.

Conclusion

We found that a critical event occurred in transit in 1 in every 20 air–medical transports of adult patients. Most often, these events were the administration of resuscitative procedures or hemodynamic deterioration. Female sex, mechanical ventilation or hemodynamic instability before transport, transport in a fixed-wing aircraft, duration of transport, on-scene calls and type of crew were independently associated with in-transit critical events. These findings may be useful in the refinement of protocols for the optimal alignment of transport resources with patients at high risk of requiring in-transit resuscitation. Our results may also inform the training of paramedic transport crews and continuing education to address the most common scenarios they face. Better understanding of the patient-level predictors of adverse events may also allow for improvements in the preparation of patients by hospital staff before transport.

This article has been peer reviewed.

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