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Trigger tool-based description of adverse events in helicopter emergency medical services in Qatar

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ABSTRACT

Introduction Adverse events (AEs) in helicopter emergency medical services (HEMS) remain poorly reported, despite the potential for harm to occur. The trigger tool (TT) represents a novel approach to AE detection in healthcare. The aim of this study was to retrospectively describe the frequency of AEs and their proximal causes (PCs) in Qatar HEMS.

Methods Using the Pittsburgh Adverse Event Tool to identify AEs in HEMS, we retrospectively analysed 804 records within an existing AE TT database (21-month period). We calculated outcome measures for triggers, AEs and harm per 100 patient encounters, plotted measures on statistical process control charts, and conducted a multivariate analysis to report harm associations.

Results We identified 883 triggers in 536 patients, with a rate of 1.1 triggers per patient encounter, where 81.2% had documentation errors (n=436). An AE and harm rate of 27.7% and 3.5%, respectively, was realised. The leading PC was actions by HEMS Crew (81.6%; n=182). The majority of harm (57.1%) stemmed from the intervention and medication triggers (n=16), where deviation from standard of care was common (37.9%; n=11). Age and diagnosis-adjusted odds were significant in the patient condition (6.50; 95% CI 1.71 to 24.67; p=0.01) and interventional (11.85; 95% CI 1.36 to 102.92; p=0.03) trigger groupings, while age and diagnosis had no effect on harm.

Conclusion The TT methodology is a robust, reliable and valid means of AE detection in the HEMS domain. While an AE rate of 27.7% is high, more research is required to understand prehospital clinical decision-making and reasons for guideline deviance. Furthermore, focused quality improvement initiatives to reduce AEs and documentation errors should also be addressed in future research.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Adverse events (AEs) may occur commonly in high-risk and uncontrolled environments such as helicopter emergency medical services (HEMS), which manages vulnerable patients owing to their critical illness or injury. However, there is little known about the true AE rates or their causes.

WHAT THIS STUDY ADDS

⇒ This study provides evidence for AE rates in a HEMS in Qatar and extends our knowledge on the proximal causes of these AEs.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Now that the proximal causes of AEs have been determined, future policies and practices may be adjusted to mitigate against and prevent these AEs from occurring. Future research may determine the effects of these changes in policy and practice, and determine their impact on patient safety and quality of care in HEMS.

INTRODUCTION

The call from the Institute of Medicine to identify and eliminate harm in the delivery of healthcare is of paramount importance, given the potential for adverse events (AEs) and patient harm to occur in these systems.[1] Due to the inherent complexities of modern day healthcare, by its nature, healthcare can be characterised as a complex adaptive system, where complicated inter/codependent variables and relationships exist, presenting opportunity for errors to occur.[2] Within this framework, two overarching perspectives towards human error exist, the person approach focusing on unsafe acts, errors and procedural violations of people at the 'sharp end', and the system approach, which conversely focuses on 'upstream' systemic factors that give rise to error traps, where the underlying assumption is that humans are fallible and will err.[2 3] Nowhere is this more evident than in the delivery of emergency care to the acutely ill or injured patient.

Healthcare delivery in the emergency department (ED) has been described as 'a laboratory for error'.[4 5] Similarly, the potential for harm to occur in the delivery of emergency care by emergency medical services (EMS) is significant, and can include a multitude of contributing factors such as fatigue, differences in provider skill and training, errors in cognition and decision-making, communication, environmental factors and team dynamics.[4 6–11] However, despite this potential, the incidence of AEs within the prehospital EMS and helicopter emergency

medical services (HEMS) remains poorly understood, with no domain-specific AE taxonomy to draw from, no standardised way of defining harm, and no uniform AE reporting mechanisms.[12–18]

Traditional methods of AE detection in healthcare typically include direct observation, morbidity and mortality review, documentation review, complaints, and voluntary reporting systems.[19 20] There is evidence to suggest that identification of AEs and harm is highly dependent on methodology employed.[20–23] The last decade has seen the emergence of the trigger tool (TT) methodology as a robust means of identifying AEs and harm in healthcare.[24–27]

Towards this, Patterson *et al* developed the Pittsburgh Adverse Event Tool (PittAETool), a consensus-based framework for identifying AEs in HEMS.[28] The tool is content validated for the domain of interest and includes by definition acts of omission and commission (identifying harm and potential for harm irrespective of outcome).[29] It, therefore, represents the most appropriate published methodology available for AE detection in HEMS. As defined by the PittAETool,[28] the aim of this study was to describe the frequency of AEs and their proximal causes (PCs) in HEMS in Qatar.

METHODOLOGY

Design

A retrospective descriptive analysis was conducted using an existing AE HEMS TT, for AEs occurring between 1 November 2016 and 31 July 2018 (online supplemental appendix 1).

Setting

The study was conducted within the LifeFlight HEMS division of Hamad Medical Corporation Ambulance Service (HMCAS), the national ambulance service of the State of Qatar. HMCAS is a two-tiered service of ambulance paramedic (AP) staffed ambulances and critical care paramedic (CCP) staffed response units, which serves a population of approximately 2.6 million people. The LifeFlight division (a 24-hour operation of 2×AW139 helicopters, each with a dual medic and stretcher configuration) is staffed by HEMS-trained paramedics (AP and CCP) and facilitates an average of 40–60 transports per month.

Instrument

The PittAETool[28] consists of 11 triggers in 4 trigger groupings: (1) documentation, (2) operational and patient movement, (3) patient condition and (4) intervention and medication triggers. The most likely PC is determined for each trigger and are divided into causes that relate to actions by patient, actions by provider, medical or vehicle equipment, environmental/scene factors or undetermined by chart review. Each PC category, excluding actions by patient, can be further classified as HEMS Crew or Non-HEMS Crew. Harm is classified on a severity scale rating as either no AE, potential harm (AE1) defined as 'an action that may lead to injury or harm, but there is no evidence that an injury or harm occurred', or confirmed harm (AE2) defined as 'an action or omission that led to injury or harm regardless of severity'.

Data sources

From 1 August 2016 to present, HMCAS established a HEMS TT database at LifeFlight as part of normal clinical governance and AE reporting practice. The following process was followed in the establishment of this database and continues as standard reporting practice at LifeFlight: each month, the HMCAS Patient Care Record (PCR) database is used to identify records for review. A documentation clerk applies eligibility criteria, prepares records, codes data and switches each teams' records for review. All HEMS records indicating a patient encounter (defined as: assessment, treatment and/or transport by ground or air) are included. All non-HEMS records are excluded. Eight HEMS-trained CCPs (two reviewers for each team) were identified, trained and provided with computer access and opportunity to practice prior to data entry. All data collection is captured on a standardised data capture template (Microsoft Excel 2010, Redwood, Washington, USA).

Baseline case and demographic data collected include: code, rater, date, incident number, PCR serial number, classification, age, case classification and provisional diagnosis. Each record is independently reviewed by two primary reviewers for the presence of a trigger. If a trigger is found, the reviewer determines the most likely PC and appropriate harm classification. If no triggers are found, the record is not reviewed further. Following each review round, the primary reviewers meet to compare findings, reach consensus and summarise results. In cases where consensus cannot be reached, a third reviewer is asked to review the case and determine outcome. All consensus data are captured on a summated spreadsheet (Microsoft Excel 2010) for analysis and AE reporting (online supplemental appendix 2).

Data collection and sampling

All cases meeting criteria for the 21-month period from 1 November 2016 to 31 July 2018 were included in the analysis (n=839). The first 3 months of data, from 1 August 2016 to 31 October 2016, were excluded to account for potential inconsistencies that may have existed in applying the inclusion and exclusion criteria, and uniformity in application of the PittAETool.[28] This sample size is mirrored in similar recent published research.[30 31]

Data analysis

Statistical analysis

Univariate descriptive analysis was conducted on all continuous and categorical variables (ie, triggers, PCs and harm classifications) using Statistica V.13.5.0.17 (2018, Tibco Software). Furthermore, in-line with the reporting standard created by Howard *et al*,[31] we reported three outcome measures: triggers, AEs and harm per 100 patient encounters. Finally, we conducted a multivariate

analysis using Stata V.15 (StataCorp. 2017. Stata Statistical Software: Release 15, StataCorp) to report any associations with harm across the dataset. We considered a p<0.05 as significant. Inter-rater reliability was not measured due to consensus methodology applied on database entry.

Quality analysis

From a quality analysis perspective, the primary outcome measures were calculated and plotted on Statistical Process Control (SPC) U-Charts using Statistica version 13.5.0.17 (2018, Tibco Software Inc.) that employed the Western Electric Rules for detecting special cause variation.[32]

RESULTS

Statistical analysis

Of the total population of HEMS patient encounters identified (n=839), 4.2% were excluded (n=35) due to missing, unknown or incomplete data. The remaining 804 patient encounters were included for analysis. The majority of patients were adults (n=702; 87.3%), between the ages of 15 and 35 (n=378; 47%). Trauma accounted for 56.5% (n=454) of records reviewed, and 65.5% of these were categorised as trauma other (n=298). Medical cases accounted for 42.9% of records (n=345) where 41% of these cases were cardiovascular (n=143). Cardiac arrest was infrequently encountered (table 1).

The PittAETool[28] identified a total of 883 trigger events over a 21-month period in 66.7% of the HEMS population (n=536), where 62.7% of these patients had 1 trigger event (n=336) and 37.3% (n=200) had 2 or more triggers. Documentation errors (n=436) occurred in 81.2% of patients whose records triggered, followed by deviation from standard of care (26.1%; n=140), high-risk interventions (14.7%; n=79), use of high-risk medications (13.2%; n=71) and worsening trend in vitals (9.7%; n=52). Excluding documentation errors, 40.3% of all triggers (n=356) occurred in the intervention and medication trigger grouping and 7.6% (n=67) in the patient condition grouping (table 2).

A total of 223 AEs were identified (table 2) with a rate of 27.7 AEs per 100 patient encounters (27.7%). Of the 536 patients whose records triggered, AEs followed in 31.3% of these (n=168), where 78.6% (n=132) had 1 AE and 21.4% (n=36) had 2 or more. The majority (72.2%) of AEs occurred in the intervention and medication triggers (n=161), followed by documentation errors 11.2% (n=25), patient condition triggers 10.8% (n=24) and operational and patient movement triggers 5.8% (n=13). While deviation from standard of care was common, accounting for 45.3% of AEs reported (n=101), medication errors contributed 12.6% (n=28), followed by failed interventions 9.4% (n=21) and worsening trend in vitals 9% (n=*20*).

Potential harm (n=195) was identified in 29.4% of patients (n=158) whose records triggered (table 2), with a rate of 24.3 potentially harmful events per 100 patient encounters (24.3%). Similarly, 74.3% came from the intervention and medication triggers (n=145), where deviation from standard of care was again frequently observed (46.4%; n=90), followed by medication errors 13.4% (n=26), failed interventions 10.3% (n=20), worsening trend in vitals 7.2% (n=14) and prolonged scene time 5.1% (n=10).

Confirmed harm (n=28) was identified in 2.6% of patients (n=14) whose records triggered (table 2), with a rate of 3.5 confirmed harmful events per 100 patient encounters (3.5%). The majority of harm (57.1%) occurred in the intervention and medication trigger grouping (n=16), followed by 34.5% in the patient condition triggers (n=10), whereas operational and patient movement triggers (specifically prolonged scene time) accounted for 6.9% of harm (n=2). Deviation from standard of care (n=11) and worsening trend in vitals (n=6) were frequent contributors to harm, 37.9% and 20.7%, respectively, followed by cardiac arrest during transport 13.8% (n=4) and medication errors 6.9% (n=2). High-risk interventions, failed interventions and use of high-risk

Table 1 Demographic summary

Classification	Category	Total	%
Cases		839	
Excluded	Missing data/unknown fields	35	
Classification	Adult	702	87.3
	Paediatric	82	10.2
	Geriatric	20	2.5
Age	Age 15–35	378	47.0
	Age 36–60	290	36.1
	Age 1–14	77	9.6
	Age 61–80	48	6.0
	Age >80	7	0.9
	Age <12 months	4	0.5
Case classification	Trauma	454	56.5
	Medical	345	42.9
	Combined	5	0.6
Diagnosis: medical	Cardiovascular	143	41.0
	Neurological	78	22.3
	Medical other	62	17.8
	Respiratory	34	9.7
	Cardiac arrest medical	32	9.2
Diagnosis: trauma	Trauma other	298	65.5
	Polytrauma	76	16.7
	Isolated head trauma	69	15.2
	Cardiac arrest trauma	12	2.6
Total		804	100.0

Table 2 Triggers, adverse events (AEs) and harm

Triggers and events by patient encounter									
		Triggers		Potential harm		Confirmed harm		Combined AEs	
Trigger	Trigger type/group	Total	%	Total	%	Total	%	Total	%
T1	Documentation errors	436	49.4	25	3.1	0	0.0	25	3.1
T2–T4	Operational/patient movement triggers	24	2.7	11	1.4	2	0.2	13	1.6
T2	Prolonged scene time*	21	2.4	10	1.2	2	0.2	12	1.5
T3	Injury to patient or self during care	0	0.0	0	0.0	0	0.0	0	0.0
T4	Request for additional resources	3	0.3	1	0.1	0	0.0	1	0.1
T5–T6	Patient condition triggers	67	7.6	14	1.7	10	1.2	24	3.0
T5	Worsening trend in vitals	52	5.9	14	1.7	6	0.7	20	2.5
T6	Cardiac arrest during transport	15	1.7	0	0.0	4	0.5	4	0.5
T7–T11	Intervention and medication triggers	356	40.3	145	18.0	16	2.0	161	20.0
T7	High-risk interventions	79	8.9	7	0.9	1	0.1	8	1.0
T8	Failed interventions*	35	4.0	20	2.5	1	0.1	21	2.6
T9	Use of high-risk medication	71	8.0	2	0.2	1	0.1	3	0.4
T10	Deviation from standard of care*	140	15.9	90	11.2	11	1.4	101	12.6
T11	Medication errors	31	3.5	26	3.2	2	0.2	28	3.5
Total		883	100.0†	195	24.3	28	3.5	223	27.7
Proportions as % of patients									
T1	Documentation errors	436	81.2	25	15.8	0	0.0	25	14.9
T2	Prolonged scene time*	21	3.9	10	6.3	2	14.0	12	7.1
T3	Injury to patient or self during care	0	0.0	0	0.0	0	0.0	0	0.0
T4	Request for additional resources	3	0.6	1	0.6	0	0.0	1	0.6
T5	Worsening trend in vitals	52	9.7	14	8.9	6	43.0	20	11.9
T6	Cardiac arrest during transport	15	2.8	0	0.0	4	29.0	4	2.4
T7	High-risk interventions	79	14.7	7	4.4	1	7.0	8	4.8
T8	Failed interventions*	35	6.5	20	12.7	1	7.0	21	12.5
T9	Use of high-risk medication	71	13.2	2	1.3	1	7.0	3	1.8
T10	Deviation from standard of care*	140	26.1	90	57.0	11	79.0	101	60.1
T11	Medication errors	31	5.8	26	16.5	2	14.0	28	16.7
Total		536	100.0	158	100.0	14	100.0	168	100.0
Proportions as % of AEs									
T1	Documentation errors	25	11.2	25	12.9	0	0.0	25	11.2
T2–T4	Operational/patient movement triggers	13	5.8	11	5.7	2	6.9	13	5.8
T2	Prolonged scene time*	12	5.4	10	5.2	2	6.9	12	5.4
T3	Injury to patient or self during care	0	0.0	0	0.0	0	0.0	0	0.0
T4	Request for additional resources	1	0.4	1	0.5	0	0.0	1	0.4
T5–T6	Patient condition triggers	24	10.8	14	7.2	10	34.5	24	10.8
T5	Worsening trend in vitals	20	9.0	14	7.2	6	20.7	20	9.0
T6	Cardiac arrest during transport	4	1.8	0	0.0	4	13.8	4	1.8
T7–T11	Intervention and medication triggers	161	72.2	145	74.3	16	57.1	161	72.2
T7	High-risk interventions	8	3.6	7	3.6	1	3.4	8	3.6
T8	Failed interventions*	21	9.4	20	10.3	1	3.4	21	9.4
T9	Use of high-risk medication	3	1.3	2	1.0	1	3.5	3	1.3
T10	Deviation from standard of care*	101	45.3	90	46.4	11	37.9	101	45.3
T11	Medication errors	28	12.6	26	13.4	2	6.9	28	12.6
Total		223	100.0	195	100.0	28	100.0	223	100.0

Denominator=804 (triggers and events by patient encounter); denominator=536 (proportions as % of patients); denominator=223 (proportions as % of AEs); denominator=195 (potential harm), 28 (harm), 223 (combined AEs).
*As defined by the PittAETool and in accordance with HMCAS Standard Operating Procedures, guidelines and norms.
†Denominator=883 (trigger events), where 37.3% of patients who triggered had 2 or more triggers (n=200).
HMCAS, Hamad Medical Corporation Ambulance Service; PittAETool, Pittsburgh Adverse Event Tool.

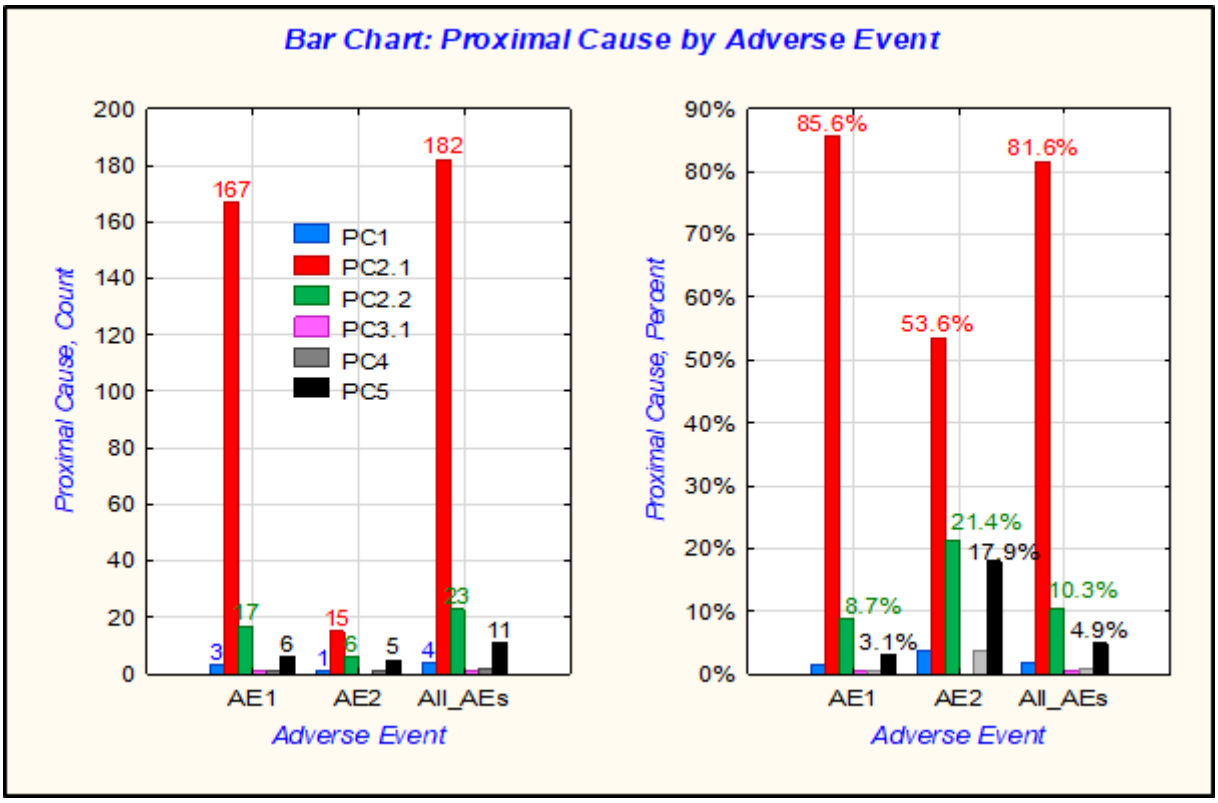

Figure 1 Proximal causes by adverse event as defined by PittAETool: PC1=actions by patient; PC2.1=actions by provider (HemS Crew); PC2.2=actions by provider (non-HEMS Crew); PC3.1=failure of medical or vehicle equipment (HEMS Crew); PC4=environmental or scene factors; PC5=undetermined by chart review. AE1=adverse event present with potential for harm; AE2=adverse event present with harm identified; All_AEs=combined adverse events and harm. HEMS, helicopter emergency medical services.

medication accounted for the remaining 3 harmful AEs identified, 3.4%, respectively.

Actions By HEMS-Crew provider (PC2.1) was the most frequent PC observed for all forms of harm identified (potential harm, confirmed harm and all AEs), occurring 85.6% (n=167), 53.6% (n=15) and 81.6% (n=182), respectively. Similarly, the second leading PC was actions by non-HEMS-Crew provider (PC2.2), occurring 8.7% (n=17), 21.4% (n=6) and 10.3% (n=23). The third leading PC was undetermined by chart review (PC5) 3.1% (n=6), 17.9% (n=5) and 4.9% (n=11) (figure 1).

For all AEs, age and diagnosis-adjusted odds were significant in the operational (25.41; 95% CI 7.31 to 88.26; p≤0.01) and interventional (62.98; 95% CI 33.80 to 117.36; p≤0.01) trigger groupings. While age had no effect, two diagnosis categories [Respiratory (10.12; 95% CI, 2.62 to 39.15; P= <0.01) and Trauma Other (3.55; 95% CI, 1.40 to 9.00; p=0.01)] showed increased odds for AEs (table 3).

Similarly, when adjusting for age and diagnosis, the odds for potential harm was significant in the operational (26.96; 95% CI 7.79 to 93.35; p≤0.01) and interventional (55.13; 95% CI 29.68 to 102.42; p≤0.01) trigger groupings. While age also had no effect, two diagnosis categories (respiratory (11.03; 95% CI 2.90 to 42.12; p≤0.01) and trauma other (3.87; 95% CI 1.53 to 9.80; p≤0.01)) again showed increased odds for potential harm (table 3).

Conversely, age and diagnosis-adjusted odds for harm were significant in the patient condition (6.50; 95% CI 1.71 to 24.67; p=0.01) and interventional (11.85; 95% CI 1.36 to 102.92; p=0.03) trigger groupings (table 3). However, age and diagnosis had no effect on harm (table 3).

Quality results

A trigger rate of 1.1 triggers per patient encounter was observed. All trigger points fell within the 3 SD, indicating common-cause variation. A run test showed four out of five counts were within 1 SD from the centre line for the months August 2017 to January 2018 (online supplemental figure 1). Furthermore, a rate of 24.3 potentially harmful events per 100 patient encounters (24.3%) was observed. All potential harm points fell within the 3 SD, indicating common-cause variation. No trends were observed ((online supplemental figure 2). Moreover, a rate of 3.5 confirmed harmful events per 100 patient encounters (3.5%) was observed. One confirmed harm point fell beyond the three SD. This indicates special-cause variation, and therefore, indicates an unstable process that is 'out of control'. A runs test showed four out of five counts were within 1 SD from the centre line for the months August 2017 to January 2018 (online supplemental figure 3). Finally, a combined AE rate of 27.7 AEs per 100 patient encounters (27.7%) was realised. All points fell within the 3 SD indicating common-cause

Table 3 Multivariate analysis

Potential harm	Odds using trigger categories	OR (95% CI)	P value
	Operational triggers	28.44 (8.70 to 92.94)	<0.01
	Patient triggers	1.19 (0.61 to 2.30)	0.62
	Interventional triggers	42.63 (23.86 to 76.16)	<0.01
	Age and diagnosis adjusted odds		
	Operational triggers	26.96 (7.79 to 93.35)	<0.01
	Patient triggers	1.65 (0.80 to 3.44)	0.18
	Interventional triggers	55.13 (29.68 to 102.42)	<0.01
	Age category		
	36–60	1.49 (0.85 to 2.60)	0.16
	>60	1.37 (0.55 to 3.42)	0.50
	Diagnosis		
	Cardiovascular	1.95 (0.76 to 5.00)	0.16
	Respiratory	11.03 (2.90 to 42.12)	<0.01
	Neurological	2.06 (0.66 to 6.39)	0.21
	Medical other	1.53 (0.44 to 5.32)	0.45
	Head trauma	1.62 (0.58 to 4.53)	0.36
	Poly trauma	2.02 (0.70 to 5.82)	0.19
	Trauma other	3.87 (1.53 to 9.80)	<0.01
Confirmed harm	Odds using trigger categories		
	Operational triggers	2.82 (0.48 to 16.68)	0.25
	Patient triggers	10.90 (3.32 to 35.71)	<0.01
	Interventional triggers	14.70 (1.78 to 121.16)	0.01
	Age and diagnosis adjusted odds		
	Operational triggers	3.02 (0.42 to 21.78)	0.27
	Patient triggers	6.50 (1.71 to 24.67)	0.01
	Interventional triggers	11.85 (1.36 to 102.92)	0.03
	Age category		
	36–60	1.97 (0.49 to 7.91)	0.34
	>60	0.77 (-0.07 to 9.10)	0.84
	Diagnosis		
	Cardiovascular	0.25 (0.04 to 1.5)	0.13
	Respiratory	1	
	Neurological	1	
	Medical other	1	
	Head trauma	0.13 (0.01 to 1.37)	0.09
	Poly trauma	0.42 (0.08 to 2.19)	0.30
	Trauma other	0.23 (0.03 to 1.51)	0.13
Adverse events	Odds using trigger categories		
	Operational triggers	27.48 (8.32 to 90.78)	<0.01
	Patient triggers	1.60 (0.80 to 3.17)	0.18
	Interventional triggers	47.78 (26.74 to 85.37)	<0.01
	Age and diagnosis adjusted odds		
	Operational triggers	25.41 (7.31 to 88.26)	<0.01
	Patient triggers	2.11 (0.99 to 4.50)	0.05
	Interventional triggers	62.98 (33.80 to 117.36)	<0.01
	Age category		
	36–60	1.72 (0.98 to 3.03)	0.06

Continued

Table 3 Continued

Potential harm	Odds using trigger categories	OR (95% CI)	P value
	>60	1.22 (0.48 to 3.07)	0.68
	Diagnosis		
	Cardiovascular	1.82 (0.71 to 4.65)	0.21
	Respiratory	10.12 (2.62 to 39.15)	<0.01
	Neurological	1.67 (0.54 to 5.20)	0.38
	Medical other	1.34 (0.39 to 4.65)	0.65
	Head trauma	1.41 (0.50 to 3.96)	0.51
	Poly trauma	2.50 (0.85 to 7.32)	0.09
	Trauma other	3.55 (1.40 to 9.00)	0.01

variation, and no trends were observed (online supplemental figure 4).

DISCUSSION

The results of this study are somewhat comparable to recent ground-based EMS literature that reported an AE rate of 4.3% and a harm rate of 0.3%.[30] However, direct comparison of AE rates within the literature is complex due to heterogeneity of data, defining harm and reporting standards.[12 14 18] While our AE and harm rates were substantially higher (27.7% and 3.5%, respectively), differences in patient acuity (eg, ground vs HEMS), provider experience and training, and sample size may explain the difference in rates observed. Furthermore, recent efforts by Howard *et al*[31 33] to adapt and operationalise the TT concept for the prehospital environment resulted in the development of the Emergency Medical Services Trigger Tool (EMSTT), where 0.34 harm events per 10 000 patient encounters was reported. When compared with the EMSTT, our harm rates were substantially higher. However, the EMSTT was designed to identify AEs in low-risk/high-frequency EMS ground transport and cannot be routinely applied to a HEMS environment with a high-risk/low frequency cohort.

Our research observed the frequent occurrence of documentation errors where Hagiwara *et al* reported similar findings.[30] There is evidence to suggest that poor quality prehospital documentation can be detrimental to patient safety and has been linked to increased mortality,[34] information loss[35] and unavailability of information in times of critical ED decision-making.[36] Moreover, inadequate documentation can hinder detection of AEs, and has the potential to underestimate the true AE rate.[37] Of interest, HMCAS coincidentally transitioned from using paper to electronic records during the study period. However, it is uncertain how this transition affected the overall quality of records and documentation of AEs, and to what degree this change influenced the record review process. Furthermore, documentation triggers were common across the reporting period, and based on the control chart for triggers, no outliers were identified (online supplemental figure 2).

Interventional and patient condition triggers (worsening trend in vitals and cardiac arrest during transport) including two diagnosis categories (respiratory and trauma other) were associated with increased odds of harm. Hagiwara *et al*[30] report similar findings, where the risk of AEs was shown to be higher in patients with 'high-risk life-threatening conditions'. From an organisational point of view, frequent AEs observed during routine clinical governance, specifically following respiratory and trauma emergencies, have led to the most changes in the associated pathways of the clinical practice guidelines in recent years.[38] Furthermore, transport stress (barometric pressure, hypoxia, thermal changes, dehydration, noise, vibration, gravitational forces, third spacing and fatigue) affect both patient and HEMS crew, and these stresses are cumulative and can lead to significant compromise.[39 40] The effect of hypoxia and increased metabolic demand may be more apparent at altitude in patients with respiratory and trauma aetiologies.[41] Moreover, some clinical interventions and patient assessments cannot be routinely performed inflight (ie, auscultation of a chest, insertion of an intercostal chest drain), and therefore, patients with severe respiratory compromise (ie, pneumothorax, asthma, chronic obstructive pulmonary disorder (COPD), pulmonary oedema) are difficult to monitor and at risk of deterioration as a consequence.[42]

Furthermore, we identified that one in five patients (17.4%) had a deviation from standard of care, and the most common cause of AEs was assigned to the HEMS crew. Again, these findings were mirrored by Hagiwara *et al*.[30] This brings into question factors that are known to influence clinical decision-making and guideline deviation (ie, fatigue, training, level of experience, interruptions to work-flow, work-load, team dynamics, communication and cognitive bias).[4 6 7 43] Moreover, guideline compliance has been shown to vary.[44] While experience, background and training may differ between healthcare providers, paramedics are dependent on guidelines and protocols.[45]

Furthermore, use of inadequate tools has been identified as a possible factor for deviation from standards of care.[46] While transport stress is cumulative (affecting both patient and HEMS crew), the link between stress and work performance is important.[39 47] HEMS crews often perform high-risk time-pressured interventions and taskings in a noisy environment where many distractions and competing priorities exist (eg, Hot-loading). Extreme environmental factors (heat and humidity) also have a cumulative effect on fatigue.[39 47] While all HMCAS HEMS crews receive formal crew resource management (CRM) training, communication can be challenging for the medical crew, especially during short mission times, when 'sterile cockpit' (periods when silence is mandated) procedures must be respected in the interest of mission safety, presenting competing communication priorities between the flight and medical crew.[48 49] Furthermore, the multicultural diversity of the work force and hierarchical nature of structures within HMCAS has the potential to create an environment not conducive to effective communication.[50] Collectively, these factors may all contribute to poor clinical decision-making and guideline deviance with the potential to compromise patient care in flight.

One strength of the PittAETool[28] is its ability to differentiate between types of harm, as not all AEs have been shown to result in harm. Furthermore, our results clearly demonstrate that potential harm (24.3%) accounted for the majority of AEs, and that intervention and medication triggers contributed significantly (74.3%). This exposes the large window of opportunity for harm to occur in our healthcare system (ie, the greater the frequency or potential for harm, the more likely harm will occur). The 'Swiss Cheese' model of system accidents and error outlines the relationship that defences, barriers and safeguards play in an accident's trajectory, and the role of human factors in error prevention.[2 3]

Lastly, from a quality standpoint, the SPC charts identified one harm point in May 2017 that fell outside the 3 SD control limit, and is, therefore, criteria for consideration of special cause variation (online supplemental figure 3). However, on review of the data, we found no reason to explain or account for this variation.[51]

The TT methodology is an accepted method for AE detection in healthcare, particularly in systems where time-constraints and resource limitations exist.[19 22 24 26 27] While more research is required to understand prehospital clinical decision-making and reasons for guideline deviance, focused quality improvement initiatives to reduce AEs and potential harm should be addressed in future research. Furthermore, efforts to understand the role of human factors in error prevention and design-proofing of our healthcare systems to reduce potential for harm should also be addressed.[8]

Limitations

While the Global TT methodology[25] typically supports the use of a small frequent sample applied consistently over time, the PittAETool[28] was applied to the entire population of HEMS Patient Encounters over a 21-month period, effectively eliminating selection bias over the reporting period. While efforts to eliminate selection bias were made, three other possible sources of bias cannot be ruled out. Information bias stemming from under-reporting of AEs is commonly associated with retrospective chart review methodologies.[37] Furthermore, the follow-up of patients was not possible as we did not have access to hospital records, and were, therefore, unable to confirm the harm reported. Lastly, the presence of any confounding factors and the degree to which they may or may not have influenced the results is not known.

The PittAETool[28] is content validated and has demonstrable internal validity. However, the external validity of the tool may be limited by factors such as case load, scope of practice, training, and experience. While Hagiwara *et al*[30] report similar AE findings, our results may not be entirely generalisable to other EMS or HEMS settings and should be interpreted cautiously. Similarly, application of the PittAETool[28] may not be transferable to other settings.

CONCLUSION

Although documentation errors were common, the majority of AEs came from the intervention and medication triggers, of which deviation from standard of care was common, and actions by the HEMS crew was the most frequent PC. Operational and interventional triggers were associated with an increased risk of AEs and potential harm, where two diagnosis categories (respiratory and trauma other) showed increased odds for AEs. Conversely, patient condition and interventional triggers were associated with increased risk of harm, where age and diagnosis had no effect on odds. While the PittAETool demonstrated a robust, reliable and valid means of AE detection in the HEMS domain, where our findings echoed those reported in recent published literature, they may not be generalisable to other EMS systems.

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Contributors CH conceived the project, collected and analysed data, drafted and edited, and approved the final manuscript. CH acts as guarantor. IH analysed data, edited and approved the final manuscript. WS analysed data, edited and approved the final manuscript.

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Competing interests At the time of the research, CH worked for Hamad Medical Corporation Ambulance Service (HMCAS). IH works for Hamad Medical Corporation Ambulance Service (HMCAS).

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available.

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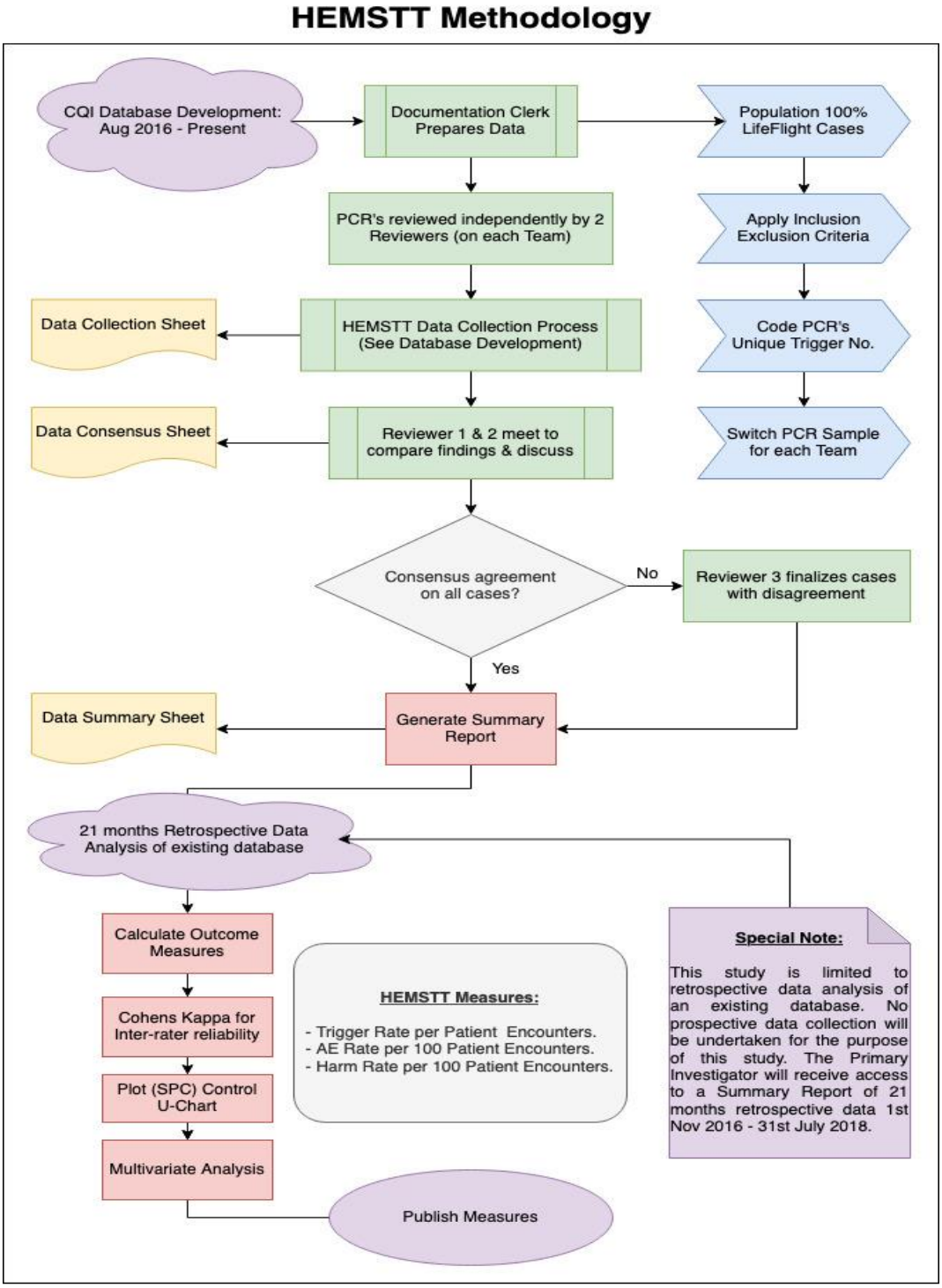
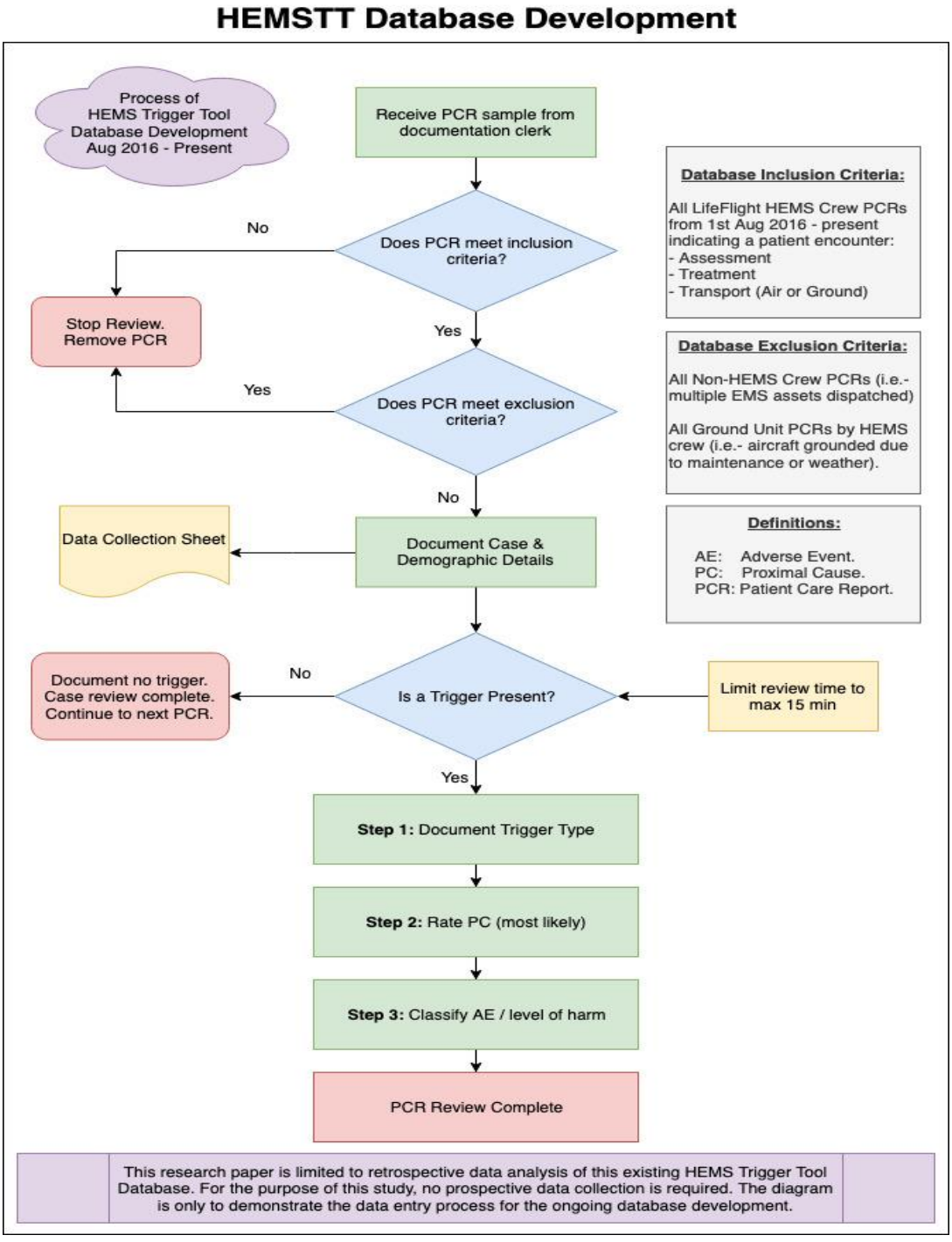
Appendix I HEMS Trigger Tool Methodology



Appendix II HEMS Trigger Tool Database Development



Supplementary figures for A TRIGGER-TOOL-BASED DESCRIPTION OF ADVERSE EVENTS IN HELICOPTER EMERGENCY MEDICAL SERVICES IN QATAR

Quality Results

A trigger rate of 1,1 Triggers per patient encounter was observed. All trigger points fell within the 3-sigma bounds, indicating *Common-Cause* variation. A run test showed 4 out of 5 counts were within 1 standard deviation from the center line for the months August 2017- January 2018 (*Figure S1, supplementary file*). Furthermore, a rate of 24,3 Potentially Harmful Events per 100 patient encounters (24,3%) was observed. All *Potential Harm* points fell within the 3-Sigma bounds, indicating *Common-Cause* variation. No trends were observed (*Figure S2, supplementary file*). Moreover, a rate of 3,5 Confirmed Harmful Events per 100 patient encounters (3,5%) was observed. One Confirmed Harm point fell beyond the 3-sigma bounds. This indicates *Special-Cause* variation, and therefore indicates an unstable process that is "out of control". A runs test showed 4 out of 5 counts were within 1 standard deviation from the center line for the months August 2017- January 2018 (*Figure S3, supplementary file*). Finally, a Combined AE rate of 27,7 AEs per 100 patient encounters (27,7%) was realized. All points fell within the 3-sigma bounds indicating *Common-Cause* variation, and no trends were observed (*Figure S4, supplementary file*).

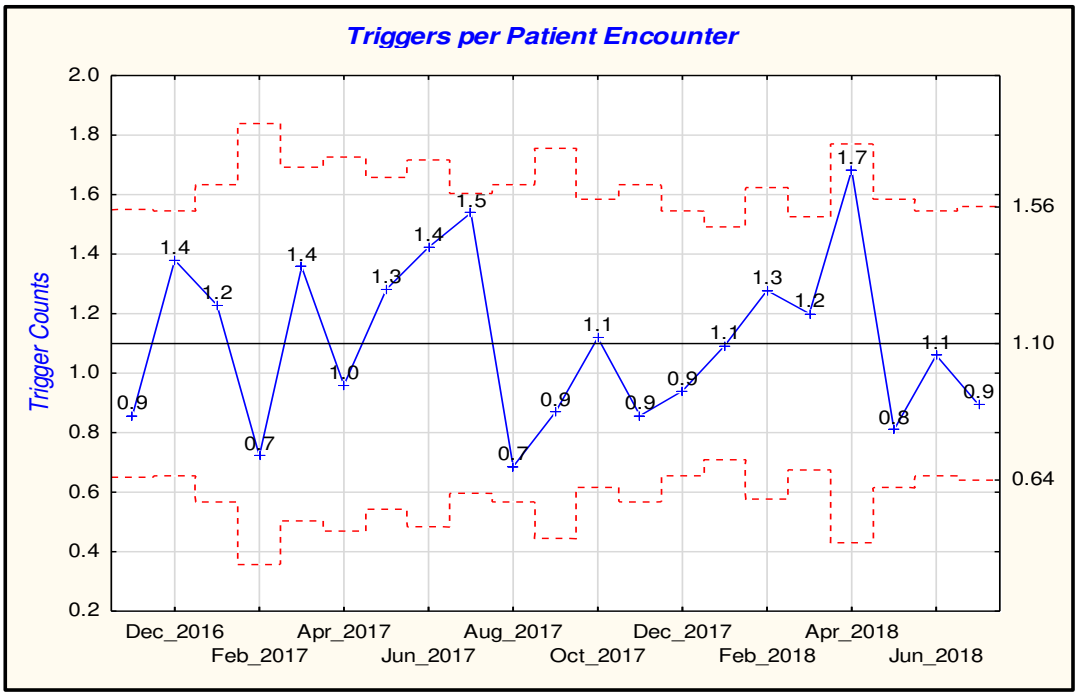


Figure S1 Triggers per Patient Encounter

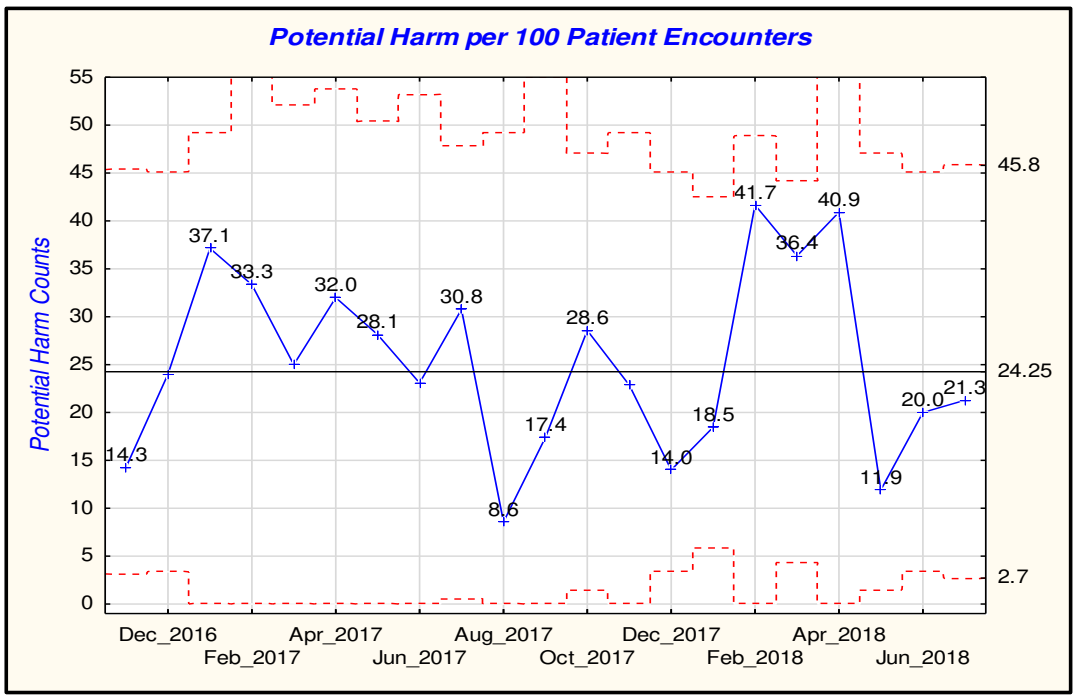


Figure S2 Potential Harm per 100 Patient Encounters

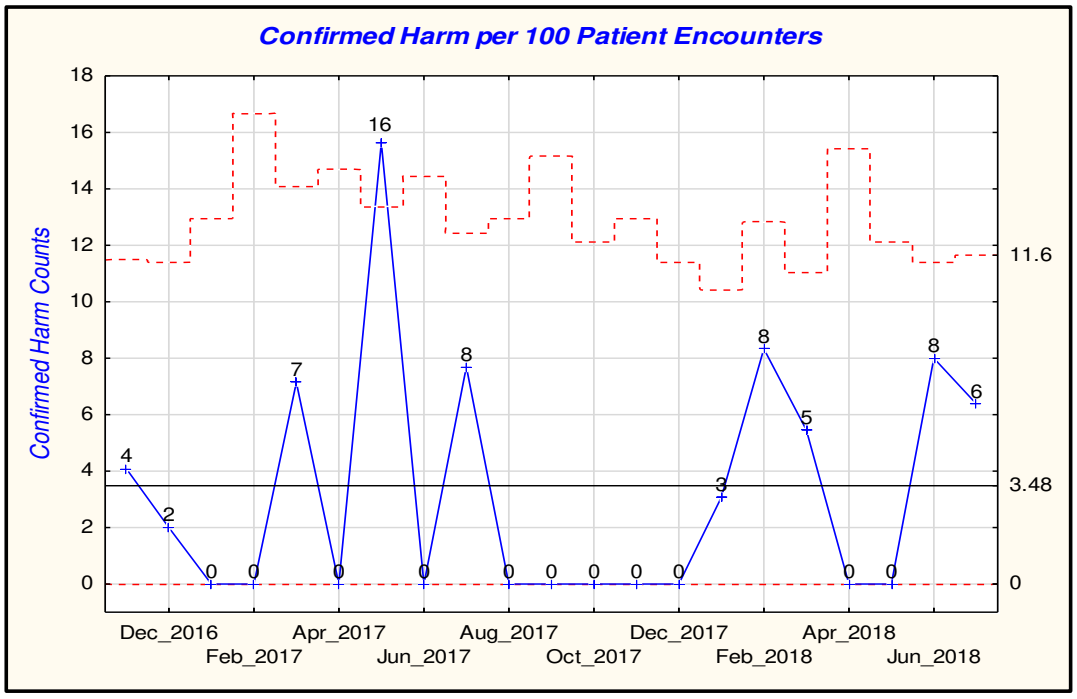


Figure S3 Confirmed Harm per 100 Patient Encounters

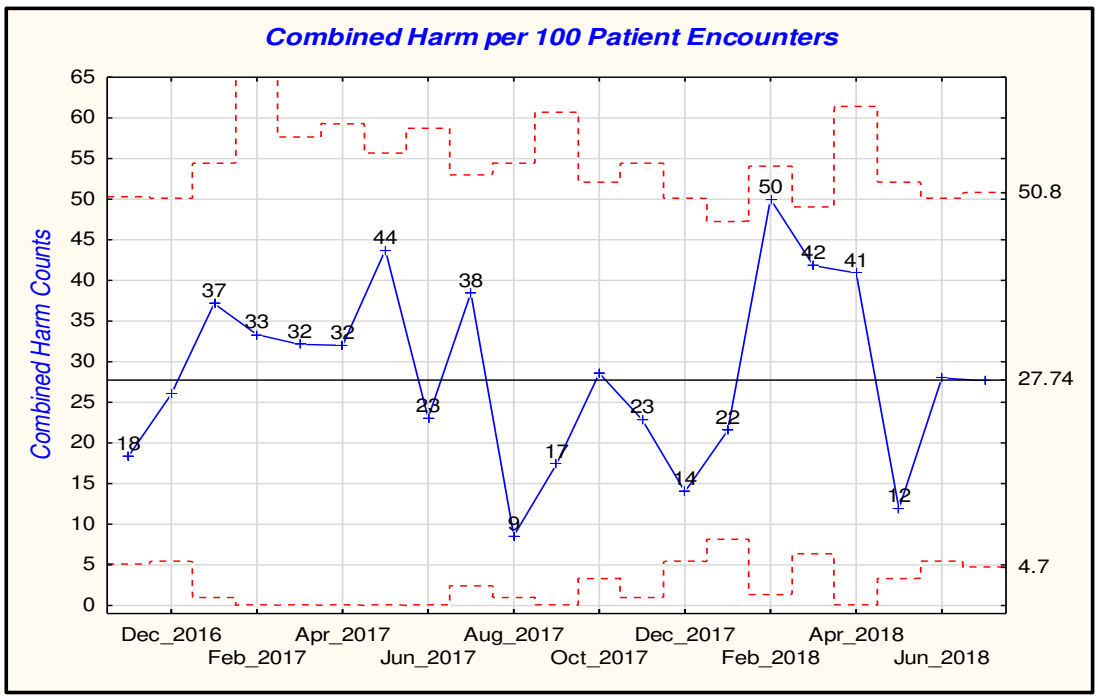


Figure S4 Combined Adverse Events per 100 Patient Encounters