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Clinical Paper

How many emergency dispatches occurred per cardiac arrest?☆

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ABSTRACT

Background: The Medical Priority Dispatch System (MPDS) is an emergency medical dispatch (EMD) system that is widely used to prioritize 9-1-1 calls and optimize resource allocation. Calls are assigned an MPDS determinant, which includes a number (1–32) representing chief complaint and priority (Alpha through Echo) representing acuity.

Objective: This study evaluates the number of emergency dispatches per cardiac arrest (NOD-CA) in cardiac arrest and non-cardiac arrest MPDS determinants.

Methods: All patients assigned a determinant by MPDS from January 1, 2008 to June 30, 2009 in a large metropolitan area were included. Prehospital electronic patient care records were linked with dispatch data. For each MPDS determinant, the number of calls for which the paramedic impression was listed as "Cardiac Arrest – Non-Traumatic" was tabulated. The NOD-CA was calculated for each cardiac arrest and non-cardiac arrest MPDS determinant. Non-MPDS calls with cardiac arrests were analyzed separately.

Results: A total of 101,642 patients were included. Among them, 555 had "Cardiac Arrest – Non-Traumatic" listed as the paramedic impression. The Cardiac/Respiratory Arrest/Death protocol had the highest number of cardiac arrests (285), followed by Breathing Problems (99) and Unconscious/Fainting (76). Overall, 183 dispatched occurred for each cardiac arrest, 131 of which resulted in a lights and sirens response. The NOD-CA was 7 in the Cardiac Arrest/Death protocol, 122 in Breathing Problems, and 104 in Unconscious/Fainting. 31 Cardiac arrests occurred in non-MPDS dispatch categories ($N = 62{,}989$), most of which were calls for medical assistance from police or fire units.

Conclusions: MPDS was designed to detect cardiac arrest with high sensitivity, leading to a significant degree of mistriage. The number of dispatches for each cardiac arrest may be a useful way to quantify the degree of mistriage and optimize EMS dispatch. This large descriptive study revealed a low NOD-CA in most cardiac arrest MPDS determinants. We demonstrated significant variability in the NOD-CA among non-cardiac arrest MPDS determinants, and few cardiac arrests in non-MPDS dispatch categories.

1. Introduction

Emergency Medical Dispatch (EMD) is a system of categorizing and prioritizing emergency calls in order to send an appropriate ambulance response. The Medical Priority Dispatch System (MPDS) is a computer-based EMD system that uses callers' responses to scripted questions to categorize cases into groups, called determinants, based on complaint and perceived acuity.

Numerous studies have examined the predictive accuracy of MPDS and other EMD systems for a variety of outcomes, including paramedic-assigned acuity score, physician diagnosis of an acute illness, "Code 3" or "lights and sirens" return, and the need for Advanced Life Support intervention.[1–18] Most research has demonstrated that MPDS and other EMD systems identify most but not all urgent calls with a considerable degree of overtriage.[7–10,12,14,16,19–21]

Cardiac arrest has been extensively studied both as a determinant and an outcome. The sensitivity in detecting cardiac arrest increased from 15% to 50% after introduction of the EMD process in one system.[22] Deviation from standard questioning was a cause of low sensitivity to properly diagnose cardiac arrest.[23] Other evaluations of the sensitivity of EMD to detect whether a patient was in cardiac arrest ranged from 55% to 88%.[2,22,24–28]

Specificity of EMD for detecting cardiac arrest varies widely. In a study of over 2000 patients assigned an MPDS determinant for

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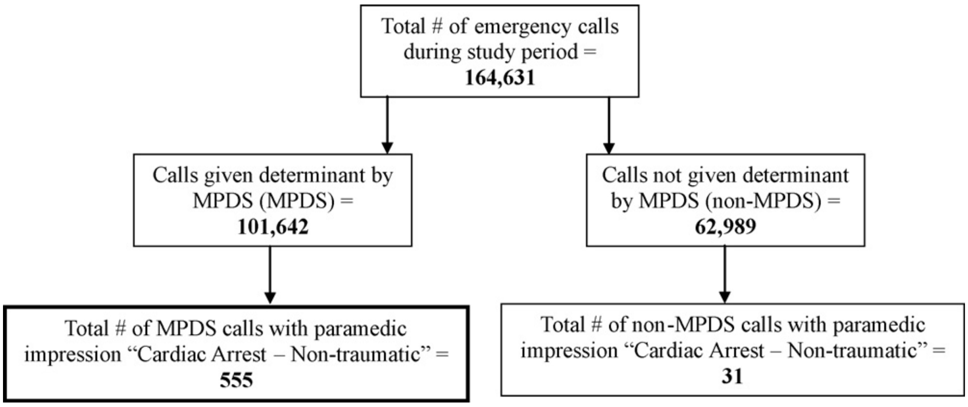


Fig. 1. Case selection and patient distribution. MPDS = Medical Priority Dispatch System.

cardiac arrest, paramedic impression was listed as cardiac arrest in only 36% of cases.[27] An Australian study showed that MPDS had a specificity of 99% for cardiac arrest.[28] It is unclear what accounts for this significant variability.

This study examines how many emergency dispatches took place for each cardiac arrest, both in MPDS determinants for cardiac arrest and in other determinants. We will also provide descriptive data about how dispatchers in our system classify calls that turn out to be cardiac arrests.

2. Methods

The City and County of San Francisco is an urban area with a population of 800,000 and a size of 47 square miles that receives approximately 60,000 calls for emergency medical assistance annually. All calls receive an Advanced Life Support response. High priority or "code 3" calls receive a "lights and sirens" response consisting of a fire department engine (staffed with one paramedic) and an ambulance staffed with at least one paramedic. Low priority or "code 2" calls receive an ambulance staffed with at least one paramedic. Most ambulances are staffed by fire department personnel, but a small percentage of calls receive private paramedic-staffed ambulance. An electronic prehospital care record is established for each patient that includes patient demographics, medical history, signs and symptoms, and clinical interventions. Additionally, paramedics enter an impression of the patient, typically after the call is completed, via a drop-down menu of standardized impressions.

9-1-1 Callers are asked a series of scripted questions that include the patient's level of consciousness, age, chief complaint, and other complaint-specific questions. A Computer-Aided Dispatch System records general information regarding each call, including date, time, and location of call, dispatch time, dispatch code, and disposition. Medical Priority Dispatch System (MPDS, Version 11.3, Medical Priority Consultants, Salt Lake City, UT) is used to categorize cases. MPDS is a computer-based dispatch system that uses callers' responses to scripted questions to categorize cases into numerical complaint-based categories called protocols, which are further assigned a priority (Alpha, Bravo, Charlie, Delta, or Echo) based on their perceived acuity. Alpha and Bravo represent the lowest acuity calls; these calls generally receive a no lights and sirens or "code 2" response in our system. Charlie, Delta and Echo represent higher acuity calls that receive a lights and sirens or "code 3" response in our system. Calls may be further assigned a numerical subgroup and a modifier, which provide responders with more specific details about the call. Together, the numerical protocol, priority (Alpha through Echo), subgroup, and modifier (when present) make up the MPDS determinant. For instance, a call may be assigned to the MPDS determinant 6D2A. The number 6 is the protocol for Breathing Problems, D (or Delta) represents priority, 2 is a subcategory which informs providers that the patient is not alert, and A is a modifier that indicates the patient has a history of asthma.

All patients from January 1, 2008 to June 30, 2009 were identified from the Computer-Aided Dispatch System and linked to an electronic prehospital care record. All patients assigned a determinant by MPDS were included in this study. A subset of emergency calls that did not go through the MPDS process (and therefore did not receive an MPDS determinant) but ended up having an ambulance dispatched and a paramedic impression listed as "Cardiac Arrest – Non-Traumatic" were analyzed separately. Most of these non-MPDS calls were thought to represent non-medical fire department calls that were either initially categorized incorrectly or evolved into a medical call, or calls for medical assistance by police or fire personnel.

The number of dispatches per cardiac arrest (NOD-CA) was calculated by dividing the total number of calls by the number for which the paramedic impression was listed as "Cardiac Arrest – Non-traumatic". The NOD-CA calculation was performed for the system as a whole, for cardiac arrest MPDS determinants, and for all other MPDS determinants in which a call was listed with the paramedic impression of "Cardiac Arrest – Non-traumatic". We elected not to analyze other paramedic impressions related to cardiac arrest, such as traumatic arrest, as doing so would be beyond the scope of a single descriptive study. Calls listed with paramedic impressions related to obvious death or "dead on arrival" were also not included in the NOD-CA calculation. MPDS determinants in which no calls had the paramedic impression of "Cardiac Arrest – Non-traumatic" were included in system-wide calculations but not reported individually as their NOD-CA would be infinity (number of dispatches divided by zero).

Absolute numbers and percentages were compared directly, and statistical significance was assessed where appropriate via a two-tailed paired *t*-test using Statistics Calculator (StatPac Inc., Bloomington, MN). The University of California, San Francisco Committee on Human Research approved this study.

3. Results

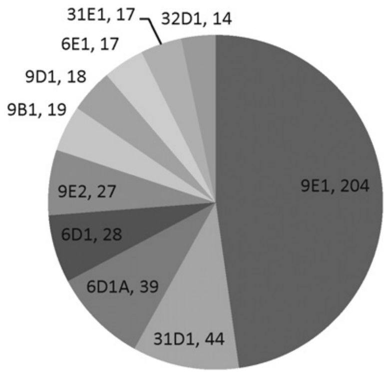
A total of 164,632 emergency calls were made to the dispatch center during the study period (Fig. 1). A total of 62,989 calls did not go through MPDS, leaving 101,642 for analysis. Among these 101,642 calls, 555 had "Cardiac Arrest – Non-Traumatic" listed as the paramedic impression. For the overall system, among coded calls, 183 dispatches occurred for each cardiac arrest.

The Cardiac/Respiratory Arrest/Death protocol (MPDS protocol 9) had the highest absolute number of cardiac arrests at 285

Table 1

Number of ambulances dispatched per cardiac arrest in each MPDS determinant for cardiac arrest determinants (a) and non-cardiac arrest determinants (b). MPDS = Medical Priority Dispatch System. # and % Arrests = # and % of calls for which the paramedic impression was listed as "Cardiac Arrest – Non-traumatic." NOD-CA = number of dispatches per cardiac arrest.

MPDS	Description	Total # calls	#Cardiac arrests	%Cardiac arrest	NOD-CA
a.					
9B1	Cardiac or respiratory arrest/death – obvious death	210	19	9.05%	11
9B1A	Cardiac or respiratory arrest/death – obvious death, cold/stiff	88	8	9.09%	11
9B1E	Cardiac or respiratory arrest/death – obvious death, non-recent	14	4	28.57%	4
9D1	Cardiac or respiratory arrest/death – ineffective breathing	536	18	3.36%	30
9D2	Cardiac or respiratory arrest/death – ineffective breathing, other	102	1	0.98%	102
9E1	Cardiac or respiratory arrest/death – working arrest, not breathing	836	204	24.40%	4
9E2	Cardiac or respiratory arrest/death – working arrest, breathing uncertain	155	27	17.42%	6
9E3	Cardiac or respiratory arrest/death – working arrest, hanging	28	1	3.57%	28
9O1	Cardiac or respiratory arrest/death – expected death	28	3	10.71%	9
		1997	285	14.27%	7
b.					
1A1	Abdominal pain	1584	1	0.06%	1584
1D1	Abdominal pain – not alert	284	1	0.35%	284
2D2	Allergies/envenomations – not alert	95	1	1.05%	95
6C1	Breathing problems – abnormal breathing	1239	8	0.65%	155
6C2A	Breathing problems – cardiac history, *asthma*	2145	1	0.05%	2145
6D1	Breathing problems – severe respiratory distress	5516	28	0.51%	197
6D1A	Breathing problems – severe respiratory distress, *asthma*	1951	39	2.00%	50
6D2	Breathing problems – not alert	440	3	0.68%	147
6D3A	Breathing problems – clammy, *asthma*	217	1	0.46%	217
6E1	Breathing problems – ineffective breathing	443	17	3.84%	26
6E1A	Breathing problems – ineffective breathing, *asthma*	136	2	1.47%	68
10A1	Chest pain – breathing normally < 35 y/o	126	1	0.79%	126
10C1	Chest pain – abnormal breathing	1252	4	0.32%	313
10C2	Chest pain – cardiac history	938	1	0.11%	938
10C4	Chest pain – breathing normally > 35 y/o	1249	1	0.08%	1249
10D1	Chest pain – severe respiratory distress	1050	5	0.48%	210
10D2	Chest pain – not alert	655	5	0.76%	131
10D3	Chest pain – clammy	1480	4	0.27%	370
11D1	Choking – not alert	80	1	1.25%	80
11D2	Choking – abnormal breathing	153	1	0.65%	153
11E1	Choking – ineffective breathing	77	4	5.19%	19
12C1E	Convulsions/seizures – pregnancy, *epilepsy*	10	1	10.00%	10
12C3	Convulsions/seizures – cardiac history	38	1	2.63%	38
12D1	Convulsions/seizures – not breathing	44	2	4.55%	22
12D2	Convulsions/seizures – continuous or multiple	1207	3	0.25%	402
12D2E	Convulsions/seizures – continuous or multiple, *epilepsy*	990	1	0.10%	990
12D3	Convulsions/seizures – irregular breathing	337	4	1.19%	84
12D4	Convulsions/seizures – breathing regularly not verified > 35 y/o	773	1	0.13%	773
13C1	Diabetic problems – not alert	584	1	0.17%	584
13D1	Diabetic problems – unconscious	199	1	0.50%	199
17B1	Falls – possibly dangerous body area	3211	1	0.03%	3211
17B3	Falls – unknown status	1946	2	0.10%	973
17D1	Falls – dangerous body area	1153	2	0.17%	577
17D3	Falls – unconscious or not alert	1105	4	0.36%	276
19D1	Heart problems/AICD – severe respiratory distress	291	2	0.69%	146
19D2	Heart problems/AICD – not alert	151	1	0.66%	151
20A1	Heat/cold exposure – alert	1	1	100.00%	1
21D2	Hemorrhage/laceration – not alert	365	1	0.27%	365
23C8I	Overdose/poisoning – unknown status, *intentional*	118	1	0.85%	118
23D1A	Overdose/poisoning – unconscious, *accidental*	29	1	3.45%	29
26A1	Sick person – no priority symptoms	4149	1	0.02%	4149
26A2	Sick person – non-priority complaints	37	1	2.70%	37
26B1	Sick person – unknown status	582	1	0.17%	582
26C1	Sick person – cardiac history	880	1	0.11%	880
26C2	Sick person – other	2	1	50.00%	2
26D1	Sick person – not alert	1277	2	0.16%	639
27D2G	Stab/gunshot/penetrating trauma – not alert, *gunshot*	54	1	1.85%	54
28C1U	Stroke – not alert, *last normal unknown*	155	3	1.94%	52
29D2	Traffic/transportation accident – high mechanism	711	1	0.14%	711
31C1	Unconscious/fainting – alert with normal breathing	378	1	0.26%	378
31C2	Unconscious/fainting – cardiac history	594	1	0.17%	594
31D1	Unconscious/fainting – unconscious	4606	44	0.96%	105
31D2	Unconscious/fainting – severe respiratory distress	40	5	12.50%	8
31D3	Unconscious/fainting – not alert	1885	8	0.42%	236
31E1	Unconscious/fainting – ineffective breathing	378	17	4.50%	22
32B3	Unknown problem (man down) – unknown status	1290	2	0.16%	645
32D1	Unknown problem (man down) – life status questionable	1853	14	0.76%	132
33A1	Transfer/interfacility – no priority symptoms	137	1	0.73%	137
33C1	Transfer/interfacility – not alert	78	2	2.56%	39
33C1T	Transfer/interfacility – not alert, *transfer*	59	2	3.39%	30
33C6	Transfer/interfacility – emergency response requested	113	1	0.88%	113
		101642	270	0.27%	376



MPDS	Description
9E1	Cardiac or respiratory arrest/death - working arrest, not breathing
31D1	Unconscious/fainting - unconsious
6D1A	Breathing problems - severe respiratory distress, *asthma*
6D1	Breathing problems - severe respiratory distress
9E2	Cardiac or respiratory arrest/death - working arrest, breathing uncertain
9B1	Cardiac or respiratory arrest/death - obvious death
9D1	Cardiac or respiratory arrest/death - ineffective breathing
6E1	Breathing problems - ineffective breathing
31E1	Unconscious/fainting - ineffective breathing
32D1	Unknown problem (man down) - life status questionable

Fig. 2. Top 10 MPDS determinants by absolute number of cardiac arrest. This depicts the distribution and absolute number of the top 10 MPDS determinants in order of absolute number of cardiac arrest. Data are listed as MPDS determinant, absolute number of cardiac arrest. Descriptions of each determinant are shown. MPDS = Medical Priority Dispatch System determinant.

(Table 1a). The NOD-CA was 7 in this protocol. The 9E1 determinant (working arrest, not breathing) had more cardiac arrests than any other MPDS determinant, and comprised over 37% of all cardiac arrests (Fig. 2). The NOD-CA in 9E1 was 4. Fewer than 5% of calls in the following determinants were cardiac arrests: 9D1 (ineffective breathing, NOD-CA 30), 9D2 (ineffective breathing, other, NOD-CA 102), and 9E3 (working arrest, hanging, NOD-CA 28).

Among non-cardiac arrest protocols, the most cardiac arrests (99) occurred in the Breathing Problems protocol (MPDS protocol 6) (Table 1b). These comprised fewer than 1% of calls in protocol 6. The NOD-CA was 122. Among determinants, 6D1A (severe respiratory distress, asthma) had the highest number of cardiac arrests at 39. (NOD-CA 50, Table 1b, Fig. 2) Between the two severe respiratory distress determinants (6D1A and 6D1), which represent patients with and without a history of asthma respectively, patients in 6D1A (with asthma) had significantly more cardiac arrests (6D1A 2%, 6D1 0.5%, $p < 0.01$).

There were 76 cardiac arrests in the Unconscious/Fainting protocol. The NOD-CA was 104 (Table 1b). The vast majority (44) of cardiac arrests occurred in 31D1 (unconscious), but these comprised less than 1% of calls in this determinant. Although 31E1 (unconscious with ineffective breathing) had a low absolute number of cardiac arrests (17), they made up 4.5% of all calls in the determinant. Five out of the 40 calls (12.5%) in 31D2 (unconscious with severe respiratory distress) were cardiac arrests. This determinant had an NOD-CA of 8.

Thirty-one cardiac arrests occurred in non-MPDS dispatch categories (Table 2). Most of the 62,989 calls that did not go through MPDS were non-medical fire department calls such as fires, building alarms, and traffic accidents. The majority of cardiac arrests in non-MPDS dispatch categories, however, occurred in calls for medical assistance by fire or police units. The majority of cardiac arrests in non-MPDS categories (17 or 55% of non-MPDS arrests) occurred in the XM (code 3 medic) dispatch category, which represents a request to dispatchers by fire, police, or EMS personnel to send an ambulance with lights and sirens. Cardiac arrests represented less than 0.2% of all calls in this category. Three cardiac arrests also occurred in the MED category, which dispatchers use to assign an ambulance to a call when adequate information cannot be obtained to complete the MPDS process in a timely manner. Again, cardiac arrests represented less than 0.2% of calls in this category.

Table 2
Distribution of cardiac arrests among non-MPDS categories. MPDS = Medical Priority Dispatch System. # and %Arrests = # and % of calls for which the paramedic impression was listed as "Cardiac Arrest – Non-traumatic.".

Non-MPDS	Description	# Calls	#Arrests	%Arrest
72E8	Surf rescue	25	1	4.00%
99M9	Transfer	18	1	5.56%
E	Dispatch engine	3265	1	0.03%
IND	Industrial accident	122	1	0.82%
MED	Medical call – initial	1594	3	0.19%
WF	Working fire	434	1	0.23%
XM	Code 3 medic	9074	17	0.19%
XMB	Life threat – medic	4	1	25.00%
XR	Code 2 ALS Ambulance	8688	3	0.03%
53B3	Code 3 medical	132	2	1.52%
	Total	23356	31	0.13%

4. Discussion

MPDS is a computer-based dispatch system designed to synthesize information from callers to categorize calls and determine an appropriate response. It was designed to be highly sensitive for cardiac arrest. This presumably leads to low specificity, and a significant degree of overtriage. The range of specificity of MPDS for cardiac arrest in prior studies has varied from 36 to 99%.[27,28] Few studies have quantified how much mistriage occurs, especially in non-arrest determinants.

The NOD-CA may be a useful measure for identifying and quantifying mistriage. In cardiac arrest dispatch determinants (those in MPDS Protocol 9), the expected NOD-CA would be low, reflecting a higher incidence of cardiac arrest in these determinants relative to the total number of dispatches. In all other determinants, one would expect a relatively high NOD-CA due to the presumably low incidence of CA. We examined both cardiac arrest and non-cardiac arrest dispatch categories and attempted to highlight determinants that deviated from this expected pattern.

In the cardiac arrest protocol (MPDS protocol 9), there were 7 dispatches for each cardiac arrest, reflecting the expected high overall incidence of cardiac arrest in this protocol. Several determinants in protocol 9 had extremely low rates of cardiac arrest and correspondingly high NOD-CAs. The 9D2 determinant (ineffective breathing, other) had an NOD-CA of 102, indicating that over 100 ambulances were dispatched for only one cardiac arrest. Another determinants (9E2 – working arrest, breathing uncertain) had an NOD-CA over 20, and several others were not far behind. These data support the notion that dispatchers using EMD struggle to diagnose cardiac arrest. They also raise questions about the utility of multiple cardiac arrest determinants and subgroups, as some are infrequently and often inaccurately applied. Previous studies have noted challenges in identifying cardiac arrest for emergency medical dispatchers.[29] Agonal breathing or "signs of life" as well as caller characteristics and anxiety have been cited as obstacles in identifying cardiac arrest.[26,29,30]

Breathing Problems (MPDS protocol 6) had the second largest absolute number of cardiac arrests and the most among non-cardiac arrest (MPDS Protocol 9) dispatches; these represented a small fraction of all calls in this protocol. The NOD-CA was high (122) as one would expect. A large study of the London Ambulance Service (LAS) found that Breathing problems make up a significant portion (16%) of EMS calls, but fewer than 1% of calls result in cardiac arrest.[31] Increasing MPDS priority was associated with higher rates of cardiac arrest. Interestingly, in the above mentioned LAS study, asthmatics had a lower rate of cardiac arrest. In our study, significantly more cardiac arrests occurred in the 6D1A determinant (severe respiratory distress, asthma) than in the 6D1 determinant (severe respiratory distress).

The Unconscious/Fainting protocol contained the third highest absolute number of cardiac arrests with an NOD-CA of 104. A prior study by our group found that the Unconscious/fainting protocol was highly sensitive (99%), but extremely nonspecific (2%) for predicting ALS interventions, a proxy for acuity.[11] Our results are in accord with previous data showing that a significant amount of overtriage occurs in this protocol. However, two determinants in this protocol, 31E1 (ineffective breathing) and 31D2 (severe respiratory distress), had high rates of cardiac arrest and low NOD-CAs. The absolute numbers of cardiac arrests in these determinants were small. It is unclear why these two determinants with respiratory-related modifiers have such high rates of cardiac arrest when compared with other determinants of similar acuity in the protocol.

Several other MPDS determinants deviated from previously described patterns. In earlier studies, approximately 6% of cardiac arrest calls were initially categorized as either seizure or chest pain.[9,14,21,22,27] In our study, fewer than 1% of cardiac arrests were assigned to these protocols (Table 1b).

Over 30 cardiac arrests occurred in non-MPDS categories. We previously reported high rates of prehospital interventions in non-MPDS categories in another EMS system.[12] To our knowledge, calls that were eventually determined to be cardiac arrests by paramedics but did not go through the MPDS process (non-MPDS) have not been previously described. Most cardiac arrests non-MPDS determinants were requests for medical assistance by police, fire, or EMS units in the field. Adding a protocol to MPDS to assist dispatchers with categorizing such calls might aid in detection of cardiac arrests or other acute events.

4.1. Limitations

This study is limited by the fact that all of its data comes from one urban community. This study also used a paramedic impression to determine whether or not a cardiac arrest occurred. Although this impression was chosen from a standardized list, there might have been some variability among paramedics in the definition of "Cardiac Arrest – Non-traumatic." A significant number of our calls did not undergo the MPDS process, which could have led to selection bias.

5. Conclusion

The number of dispatches for each cardiac arrest may be a useful way to quantify the degree of mistriage and optimize EMS dispatch. This descriptive study of over 100,000 calls revealed a low NOD-CA in most cardiac arrest MPDS determinants. Several cardiac arrest determinants had few cardiac arrests and a high NOD-CA, which might bring into question their utility. A large number of cardiac arrests occurred in non-cardiac arrest determinants, among which we demonstrated significant variability in the NOD-CA. Some cardiac arrests occurred in calls that did not go through MPDS, many of which were calls for assistance by police or fire personnel.

Conflict of interest

KAS receives compensation for medical direction from American Health and Safety Training, Inc. and the San Francisco Fire Department.

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Case Conference

Complex Extrication and Crush Injury

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Abstract

An unusual motor vehicle collision case is presented involving a complex, prolonged extrication with crush injury. While crush injury and crush syndrome are often considered to be in the realm of disaster medicine and urban search and rescue, more typical single-patient or few-patient incidents such as industrial accidents and vehicular crashes can involve these clinical entities. All emergency medical services (EMS) personnel should have a basic working familiarity with the operational and clinical issues involved in crush injury and crush syndrome. Crush syndrome is reviewed here from the perspective of prehospital management. **Key words.** emergency medical services; traffic accidents; rescue work; crush syndrome; sodium bicarbonate; emergency medical technicians; extrication

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Case Report

At approximately 0555 hours on an October weekday, a sedan being driven by a 27-year-old man collided at moderate speed with the rear of a stopped garbage truck (Fig. 1). Two sanitation workers were standing directly behind the truck, loading trash into the truck. They were both pushed under the back of the truck by the car and ended up lying on the hood of the car, with their feet over the front bumper of the car and their legs and their abdomens wedged between the car hood and the underside of the back of the truck. Their heads were driven through the windshield of the car on impact, and both ended up lying with their heads on the dash of the car, looking up at the ceiling of the car. Bystanders called 9–1-1 as the driver of the sedan exited his car, uninjured.

First-arriving fire department personnel were told by a bystander that everybody was out of the car. However, they immediately discovered the two trapped sanitation workers, and a quick size-up of the scene indicated that a complex and potentially lengthy extrication would be needed. Additional fire department rescue units were requested by the incident commander (IC). The state air medical service was unavailable because of weather (light rain and fog). The fire department paramedic requested dispatch of the regional physician response team.

The fire department paramedic began assessment of patient 1 (on the driver's side of the hood), while his emergency medical technician-basic (EMT-B) partner began assessment of patient 2 (on the passenger's side of the hood). High-flow oxygen was applied to each patient. Because of the windshield glass surrounding (and in effect partially stabilizing) each patient's neck, it was not feasible to apply cervical immobilization. An emergency medical services (EMS) physician (DCC) and an EMS physician assistant/EMT-paramedic (KB) from the physician response team arrived approximately 20 minutes into the case, and reported to the IC. Additional fire department and private ambulance service EMS assets arrived at approximately the same time, resulting in enough advanced life support (ALS) personnel for dedicated attention to each patient, as well as the driver of the car, who ultimately agreed to be transported to the hospital despite an apparent lack of injuries.

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Dr. Portereiko was at the Section of Trauma and Critical Care, Department of Surgery, Yale University School of Medicine, New Haven, Connecticut, at the time of this case.

Drs. Cone and Portereiko have served as Medical Team Managers for Connecticut Urban Search & Rescue Task Force 1.

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Figure 1 Overview of the scene after extrication of the two patients.

Figure 2 . Three sets of cribbing and high-pressure air bags were used to lift the rear of the truck off the hood of the car. In addition to the set shown here, an identical set on the left-hand side of the truck and a third set under the truck just in front of the car's bumper were used.

After assessing the scene and the patients, the EMS physician provided a brief radio report on each patient to the area level I trauma center that was the intended destination for both patients. Each patient had large-bore intravenous access established prior to extrication, and lactated Ringer's solution was changed to normal saline for bolus infusion. On the advice of the physician response team, each patient was also given 1 ampule (44 mEq) of 8.4% sodium bicarbonate immediately before extrication because of the likelihood of a significant crush injury to the soft tissues of the lower extremities and pelvis and the possibility of crush syndrome, given the substantial pressure to the area between the hood of the car and the underside rear of the truck. Continuous electrocardiogram (ECG) monitoring was performed to watch for dysrhythmias and changes in QRS morphology and width.

After protecting the patients as much as possible, the fire department was able to raise the rear of the garbage truck with three sets of high-pressure air bags and cribbing (Fig. 2). Careful coordination of the three lifting rigs was needed, and a safety officer monitored the effects of the operation on the two patients. While initially the car rose simultaneously with each raise of the truck (since the front end of the car had been pushed down on its springs at impact), eventually the car stopped rising, and enough space was created between the underside of the back of the truck and the hood of the car to allow for removal of the patients. The IC had requested a large crane from a local contractor as a backup plan, to lift the truck off the car; the crane was only a mile from the scene when extrication was completed. Total entrapment time was over an hour.

After extrication, spine immobilization and packaging were completed, the patients were briefly reassessed, and transport to the trauma center was initiated by ground.

Patient 1 was a 28-year-old Hispanic man with no past medical history. On arrival at the trauma center, his vital signs were documented as a blood pressure of 110/82 mmHg, pulse rate of 155 beats/min, respiratory rate of 20 breaths/min, and oxygen saturation of 99% on a non-rebreather mask. The primary survey was unremarkable. The secondary survey was significant for multiple lacerations of the face, neck, chest, and scrotum. The right lower extremity showed multiple abrasions without deformity, and the left lower extremity showed midtibial deformity and crepitus. Portable x-rays of the chest and pelvis in the trauma bay were negative. Computed tomography (CT) scans of the head and cervical spine revealed irregularity of the left globe, but were otherwise negative, as was a CT angiogram of the neck. CT scans of the chest, abdomen, and pelvis showed questionable compression fractures of T4, T5, T6, and T8 with some paravertebral hematoma. Plain films of the right lower extremity showed a tibial plateau fracture, while films of the left lower extremity showed a metaphyseal tibial fracture. Initial blood testing was significant for a creatine kinase (CK) level of 2,000 U/L (normal range 24–195 U/L; rhabdomyolysis is defined as at least 5 to 10 times normal).

Patient 2 was a 41-year-old Hispanic man with no pertinent past medical history. His vital signs on emergency department (ED) presentation were a blood pressure of 90/69 mmHg, pulse rate of 124 beats/min, respiratory rate of 28 breaths/min, and oxygen saturation of 100% on a non-rebreather mask. The primary survey was unremarkable. The secondary survey showed a deformity of the right ankle with an open fracture, and deformity of the left ankle. Portable chest x-ray showed first, second, and fourth right rib fractures. CT scan showed the following: contour deformity of the inferior vena cava, concerning for thrombosis; circumferential stranding around the aorta, concerning for aortic wall injury; a small amount of hemoperitoneum without evidence of bowel injury; bilateral fractures of the anterior pubic rami; fracture of the left acetabulum; and a nondisplaced sacrum fracture. Further x-rays revealed fractures of the right calcaneus and right talus, multiple comminuted fractures of the right distal tibia and fibula, and fracture of the left lateral malleolus. Initial blood testing was significant for a CK level of 2,580 U/L, a lactic acid level of 10.6 mmol/L, a serum bicarbonate level of 13.1 mmol/L, and a creatinine level of 1.7 mg/dL. Initial urinalysis was also positive for urine myoglobin.

Patient 1 was taken to the operating room, where he underwent closed reduction and external fixation of the left proximal tibia, and repair of his numerous lacerations. He was admitted to the surgical intensive care unit, where he received intravenous antibiotics and frequent neurovascular checks on his lower extremities. On postinjury day 5, he was taken back to the operating room for removal of the external fixator and open reduction and internal fixation of the right and left tibia fractures.

Serial monitoring of the patient's creatine kinase level displayed a peak level of 8,320 U/L on postinjury day 1. Within five days after the initial injury, the level had returned to 4,400 U/L. No additional bicarbonate was needed. On postinjury day 8, the patient was discharged to a rehabilitation facility.

Patient 2 was taken to interventional radiology, where he underwent vascular studies of the lower extremities, pelvis, and abdominal aorta. These studies revealed vascular compromise of the right lower extremity due to an acute angulation of the anterior tibial artery at the site of the comminuted tibia–fibula fracture. This patient was also taken to the operating room, undergoing irrigation and debridement of the right tibia and fibula, reduction and external fixation of the right tibia and fibula, and irrigation and debridement of the left ankle.

The patient had a prolonged stay in the surgical intensive care unit, during which he was taken back to the operating room on several more occasions for revision of the right lower extremity injury, and for a decompressive laparotomy on postinjury day 3, which became necessary after the patient developed an abdominal compartment syndrome.

On serial monitoring, the creatine kinase level peaked on postinjury day 1 at 14,700 U/L, which returned to a level below 1,000 U/L by day 8. The creatinine level normalized to 1.2 mg/dL by postinjury day 2, as did the lactic acid level (1.2 mmol/L). By postinjury day 30 he was extubated, and on postinjury day 58 he was discharged from the hospital to a local rehabilitation facility.

DISCUSSION

Events of the last decade have led to an increased awareness of disaster medicine in the EMS community, with an important component of this being knowledge of crush injury and crush syndrome. While this clinical entity is frequently associated with major events such as earthquakes, building collapses, and terrorist attacks, it is important to remember that it may occur in incidents of a much smaller scale.[1] Numerous cases of crush syndrome have also been reported in nontrauma scenarios, such as drug overdoses or carbon monoxide poisoning.[2] Rendered immobile by a medical condition, the patient's own body becomes the source of tissue compression, such as the torso of an unconscious patient coming to rest on his or her own leg. Any condition that results in prolonged immobility can theoretically induce a crush injury.

Crush syndrome has been reported since the early portion of the 20th century. Dr. Bywaters, a British nephrologist, first documented the signs and symptoms of what we now know as crush syndrome.[3] During the bombing of London in 1941, he was involved in the care of four apparently healthy-looking patients who had been trapped for extended periods of time in the rubble of collapsed buildings. Soon after initial presentation to the hospital, the patients became pale, diaphoretic, and hypotensive, and eventually died. Bywaters and Beall described a common group of signs and symptoms in the four patients: oliguria/anuria, hyperkalemia, uremia, anxiety, generalized edema, hypotension, and death. Postmortem examination revealed muscle necrosis, along with degenerative changes and brown pigment casts in the renal tubules.[3]

Crush syndrome was also studied in later decades, frequently among victims of earthquakes, mine collapses, and bombings. The 1976 earthquake in Tangshan, China, resulted in 242,769 deaths and 361,300 injuries. Twenty percent of these patients were found to have suffered from crush syndrome. Crush syndrome was found to be the leading cause of death for those who reached medical care after the Armenian earthquake of 1988.[4]

Crush syndrome has been characterized as "a form of traumatic rhabdomyolysis that occurs after prolonged continuous pressure and characterized by systemic involvement."[5] It likely takes roughly four hours of compression for true crush syndrome to develop,[6] though this has not been studied in an organized manner. Prolonged compression of skeletal muscle results in inadequate local perfusion, as well as direct trauma to the muscle tissue, with three resulting effects. First, the compromised cells begin leaking toxic substances such as potassium, myoglobin, urate, and phosphate, resulting in nephrotoxicity and cardiotoxicity. Second, the damaged cell walls also begin allowing sodium, calcium, and water to move intracellularly, resulting in intravascular volume depletion and further electrolyte shifts.[7] Third, local hypoxia results in anaerobic cell function, and as a result lactic acid is produced. All of these effects take place locally until the compressive force is removed. As blood flow resumes, the accumulated toxins are released systemically. It is believed to be this systemic release that accounts for the sometimes rapid deterioration of an extricated patient, despite appearing relatively stable during prolonged periods of entrapment.

The crush syndrome patient's presentation may initially be relatively benign. Prior to release from entrapment, the patient may only complain of extremity pain. A distal pulse may or may not be palpable. There may be complaints of swelling and pain in the compressed extremity, along with physical signs of injury such as ecchymosis. The weak or absent pulse may indicate that vascular compromise has already begun to occur. The limb eventually becomes swollen, pale, and cool to touch, and often loses sensation. After limb release, systemic consequences gradually develop. The loss of intravascular volume due to a combination of bleeding and intracellular fluid shifts results in hypotensive shock due to hypovolemia. The elevated serum potassium level[8] due to loss of muscle cell integrity may cause ECG changes: initially peaked T waves and shortened QT segments, and as potassium levels increase further, QRS widening, "sine wave" complexes, and eventually ventricular fibrillation or asystole. Ventricular fibrillation may also develop as a result of the lactic acidosis. ECG monitoring is thus more important in crush patients than in other trauma patients.

Renal failure is another serious consequence of crush syndrome. Elevated myoglobin levels cause precipitation in the distal convoluted tubules, leading to tubular obstruction. Secondary injury to the renal system is also caused by the vasoconstriction and tissue ischemia that are a result of the systemic hypovolemic shock. Some have described a bimodal distribution of deaths, with early deaths due to cardiac issues, and delayed deaths due to renal issues or to infection at the traumatized area.

Management of crush syndrome should be begun as early as possible, preferably prior to release of the compressing force and extrication.[9] Attention to airway, breathing, and circulation is paramount, as with any trauma patient, and scene safety must be carefully considered given the frequently hazardous circumstances of these cases. The mainstay of crush syndrome therapy is aggressive fluid resuscitation with 0.9% saline. An initial rate of 1–1.5 L/hour is suggested (10–15 mL/kg/hour), which can be adjusted depending on the clinical status of the patient.[8] Potassium-containing intravenous solutions (e.g., lactated Ringer's) should likely be avoided because of the frequent occurrence of hyperkalemia in this patient population, though no comparative studies of various fluids have been performed.

The primary medication given in the field is sodium bicarbonate, which is routinely available on standard paramedic units. Sodium bicarbonate provides multiple therapeutic benefits. Bicarbonate administration is also helpful in treating the lactic acidosis and hyperkalemia that are associated with crush syndrome. Alkalinization of the urine assists in preventing acute renal failure by reducing urine cast formation and directly diminishing the toxic effects of myoglobin.[10] Dosing recommendations vary, but in general at least 50–100 mEq of 8.4% sodium bicarbonate (1 mEq/kg) should be administered prior to limb release. Bicarbonate may also be added to the intravenous fluids the patient is receiving. There is controversy regarding whether the administration of calcium, also commonly available on ALS units, is helpful or harmful.[11] While mannitol is likely to be helpful in patients with inadequate urine output,[12,13] this medication is not generally available in the field, and typically is not needed in the time frame of the standard EMS encounter. The combination of fluids, bicarbonate, and mannitol, sometimes referred to as the "crush injury cocktail," has been shown to be beneficial[14] and should be considered and utilized as the clinical and logistic circumstances permit. While furosemide is readily available on most ALS units (though its use is falling out of favor for prehospital treatment of congestive heart failure), it is not indicated in cases of crush syndrome, even in the presence of decrease urine output.[15]

Given the potential for "nondisaster" presentation of crush syndrome and the importance of prehospital treatment, it is important for the EMS medical director to ensure that each EMS system takes the necessary steps to prepare for this type of patient. At a minimum, the medical director should ensure that all paramedics are well educated in the presentation, pathophysiology, and management of crush injury and crush syndrome; it should not simply be the realm of urban search-and-rescue (US&R) personnel. A number of reviews of crush injury and treatment are available.[16–19]

This case also served to highlight the importance of a strong line of communications between the field providers and the EMS medical oversight. Our system has the relative luxury of the availability of a physician response team for on-scene consultation with the EMS providers. There is little documentation of the current prevalence of physician response teams within EMS systems in the United States. A 1997 survey of the 125 most populous U.S. cities showed that only 29% of respondents had some form of a physician field response team in their EMS systems,[20] but we are not aware of more recent data. Our local experience has been that the field providers appreciate the availability of real-time medical oversight on more complex situations such as the case described. Frequent interaction with the field providers also helps develop a level of comfort between the EMTs/paramedics and the physician field response team members. By periodically responding to routine calls and participating frequently in drills and continuing medical education sessions, there is a greater opportunity to interact with the field providers and increase their degree of comfort with the presence of medical oversight personnel on scene. In EMS systems that do not have the option of physician response to scenes, it is probably beneficial to stress the role of early involvement of direct medical oversight in complex cases such as the extrication described here.

CONCLUSION

This case demonstrates the combination of operational and clinical actions needed to optimize outcomes in a complex, prolonged extrication. Knowledge of the physiologic principles and basic field treatment strategies for crush injuries should be commonplace among field personnel and EMS physicians, as these injuries can occur outside of the disaster/US&R realm.

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