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Delayed family reunification of pediatric disaster survivors increases mortality and inpatient hospital costs: a simulation study

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ABSTRACT

Background: Disasters occur randomly and can severely tax the health care delivery system of affected and surrounding regions. A significant proportion of disaster survivors are children, who have unique medical, psychosocial, and logistical needs after a mass casualty event. Children are often transported to specialty centers after disasters for a higher level of pediatric care, but this can also lead to separation of these survivors from their families. In a recent theoretical article, we showed that the availability of a pediatric trauma center after a mass casualty event would decrease the time needed to definitively treat the pediatric survivor cohort and decrease pediatric mortality. However, we also found that if the pediatric center was too slow in admitting and discharging patients, these benefits were at risk of being lost as children became "trapped" in the slow center. We hypothesized that this effect could result in further increased mortality and greater costs.
Methods: Here, we expand on these ideas to test this hypothesis via mathematical simulation. We examine how a delay in discharge of part of the pediatric cohort is predicted to affect mortality and the cost of inpatient care in the setting of our model.
Results: We find that mortality would increase slightly (from 14.2%–16.1%), and the cost of inpatient care increases dramatically (by a factor of 21) if children are discharged at rates consistent with reported delays to reunification after a disaster from the literature.
Conclusions: Our results argue for the ongoing improvement of identification technology and logistics for rapid reunification of pediatric survivors with their families after mass casualty events.

1. Introduction

Disasters, both natural and man-made, have long caused significant direct injuries. This has been demonstrated most recently by the 2004 Indian Ocean tsunami [1]; Hurricane Katrina, which devastated the Gulf Coast of the United States in 2005 [2]; the Haitian and Chilean earthquakes of 2010 [3]; the tsunami and associated Fukushima Daiichi nuclear disaster of

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Japan in 2011 [4]; and most recently, by hurricane Sandy, which wreaked havoc in New England in 2012 [5]. The potentially large number of survivors who are affected may require medical evaluation and treatment and can overwhelm the health care resources of hospitals in the affected areas. Disaster planners have sought the best systems to triage and treat the resulting "disaster surge" [6], but the unpredictability and variability of these events are significant challenges [7].

Given the random nature of disasters, mathematical models offer a powerful tool in addressing the optimal preparation for, and distribution of health care resources during and after, a mass casualty event resulting from a disaster [8]. The optimal distribution of resources has been studied in the field of queueing theory [9]. In particular, when the number of patients is large, their behavior from a logistical point of view can be approximated by what are referred to in the queueing theory literature as fluid models [10]. In this approach, the mathematical details include solving ordinary differential equations for how patients flow to and from various states or "compartments" such as admitted *versus* not admitted or alive *versus* dead. Such simulations are also referred to as compartmental models. This method has been successfully applied to the threat of anthrax bioterrorism [11] and pandemic influenza [12].

In a previous publication, we developed a compartmental model of patient flows after a disaster, with a focus on pediatric survivors. We constructed a simulation to model the effect on time to treatment and total mortality in the presence and absence of a pediatric trauma center (PTC) to assist with the treatment of child survivors [13]. In that work, we found that the availability of a PTC to victims of a mass casualty disaster would decrease the time to triage and treatment of the entire disaster patient surge, as well as decrease the relative mortality by 37%. A significant fraction of disaster survivors are almost always children, who have special medical, surgical, and psychosocial needs, which can be met efficiently by a PTC [14]. However, children who are triaged and admitted to a hospital for treatment of disaster-related injuries cannot simply be discharged after treatment. They must be discharged into the custody of a parent or guardian. In the setting of a disaster, infrastructure and communications may be compromised and family separation can ensue, resulting in significant delays in discharge of pediatric patients from the hospital. In this work, we sought to quantify the effect of such delays on both total inpatient cost and mortality of the cohort of surge survivors.

2. Methods

We have described the mathematical formulation of our simulation in detail elsewhere [13]. In brief, a disaster occurs, producing an instantaneous surge of patients who require triage and treatment. In this work, all patients are assumed to be children. Equivalently, the model can be thought of as focusing only on the pediatric component of a real disaster surge. Pediatric patients then wait to be admitted to a PTC. Once admitted, they are tracked as two separate cohorts, those who can be discharged rapidly because of ready availability of family or other caregivers to take custody of them once they are treated, and a second cohort whose discharge is slower and remain hospitalized because of delayed reunification with family. Figure 1 displays a conceptual diagram of how patients move through various "compartments" in the model: initial surge, rapidly reunified cohort, slowly reunified cohort, and discharged patients. The patients may leave each compartment either by passing along to the next one with rates indicated by the subscripted Roman letters k or can die with rates indicated by the subscripted Greek letters ω. The admission rate k_a and the discharge rate of the fast reunification cohort $k_{d,\ fast}$ are set to the fitted values from our previously published analysis [13] of the Israeli Defense Forces (IDF) mobile hospital that operated in Haiti after the 2010 earthquake [15]. The mortality rate for each compartment, ω_s, ω_{fast}, ω_{slow}, and ω_d for the initial surge, rapid and delayed reunification cohorts, and discharged patients, respectively, are set to previously reported mortality rates from the disaster literature as we describe further in the Appendix. The values for all fixed parameters, including those given in the Appendix, are shown in the Table.

There are two adjustable parameters in the present work. These are the delayed reunification rate $k_{d,\ slow}$, which we vary from near zero (10^{-15}/d) to just over the fitted value for the rapid reunification rate $k_{d,\ fast}$, and the reunification rate when all hospital beds are occupied, $k'_{d,\ slow}$. We varied them in such a way that the two values were equal until $k'_{d,\ slow}$ reached that obtained from the IDF field hospital in our previous article (0.122/d), after which only $k_{d,\ slow}$ was increased.

This method of varying the reunification rates was chosen to allow for the best comparison with our base case of the IDF field hospital. We note that in the base case, the fitted value for $k_{d,\ slow}$ is 1.151 ± 0.377/d, whereas that for $k'_{d,\ slow}$ is 0.122 ± 0.014/d [13]. In the present work, for very small values of $k_{d,\ slow}$, we did not want the effects on mortality or cost to be artificially dominated by a relatively much larger value of

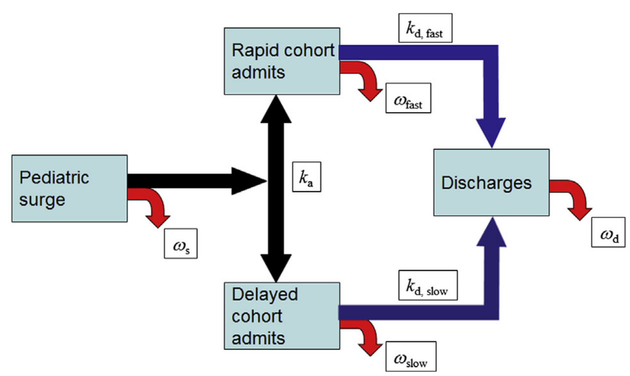

Fig. 1 – Schematic of patient flow through the delayed reunification model. The light blue boxes indicate the separate compartments through which the patients may move: the initial surge of disaster victims, admission to hospital as part of either a rapidly discharged or delayed reunification cohort, and discharge. The arrows indicate the direction and destinations of movement. In particular, the red arrows indicate patient deaths. The rate constants k_i and ω_i are explained in detail in the text but conceptually are the fraction of the initial surge per unit time that flows down an arrow from one compartment to the next. (Color version of figure is available online.)