TRIAGE STRATEGIES FOR MULTIPLE AVALANCHE BURIALS – A MONTE CARLO SIMULATION

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ABSTRACT: Settings with multiple avalanche burials and a limited number of rescuers require triage strategies, i.e. guidelines for rescuers as to where to devote their attention and actions. We here consider a scenario with one rescuer and two avalanche victims both requiring attention. The first avalanche victim has been found and excavated, is unconscious and needs resuscitation, while the second victim is still buried. What should you do? Resuscitate the first, or search for the second – who maybe is not deeply buried? Our aim is to find the optimal strategy which on average maximises the number of survivors without favouring either the first or second victim – according to the concept of the «greatest good for the greatest number». As avalanches statistics are insufficient to solve this optimization problem, we performed Monte Carlo simulations for calculating survival probabilities and average numbers of survivors. The Monte Carlo approach enables us to incorporate empirical, data based distributions of required variables, such as search time or burial depth. Our Monte Carlo simulation reveals new optimized values for the duration of resuscitation that differ from previous, mainly case-based assumptions.

KEYWORDS: avalanche rescue, Monte Carlo simulation, triage, cardiopulmonary resuscitation

1. INTRODUCTION

Whereas in many countries the total number of avalanche victims did not increase during the last decade (e.g., Techel et al., 2016) the number of avalanche incidents with multiple victims has increased in recent years in many countries such as Norway, Canada, France, and Switzerland. For instance, in Switzerland, the number of people involved in fatal avalanche accidents has increased by almost 50% in the five years from 2008-2009 to 2012-2013 compared to the preceding 5-year period. At the same time the number of accidents with three or more fatalities has doubled as well (Schweizer, 2014). This suggests that avalanche accidents where several persons require rescue and medical assistance (Fig. 1) might increase and therefore specific triage strategies for this kind of «mass casualty incidents» are required (Genswein, 2013). Accordingly, refined rescue concepts are being developed involving both the safety of the rescuers and also an optimal strategy for the treatment and excavation of victims.

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Fig. 1: Avalanche victim (dummy) needing resuscitation. Photo: Craig A. Borthwick - Venture Medical UK.

Apart from technical developments, e.g. improving the performance of avalanche transceivers, it hence seems most promising to improve avalanche rescue by optimizing rescue procedures with a view towards the highest possible survival chances (e.g. Genswein et al., 2014; Genswein et al., 2009) for the avalanche victims – also known as the «greatest good for the greatest number» (Jeremy Bentham, 1748-1832).

Based on Bentham's consideration Bogle et al. (2010) developed the Avalanche Survival Optimizing Rescue Triage (AvSORT) algorithm. They made theoretical considerations based on medical data and estimated survival probabilities of avalanche victims under different circumstances. They state that "it would be for the greater benefit of the whole to extract potential survivors that risk asphyxia while buried rather than engage in protracted resuscitation on probable nonsurvivors". This is exactly the point we focus on with this work using probabilistic, data-based calculations.

Our aim is to provide a survival chance optimized triage strategy for a simple rescue scenario with two fully buried subjects and one rescuer. As avalanche statistics are insufficient to solve this optimization problem, we performed Monte Carlo simulations for calculating for calculating survival probabilities and average numbers of survivors.

2. METHODS

The Monte Carlo method is a numerical method to solve mathematical problems by repeated random sampling (Sobol, 1994). We use the method to calculate expectation values of quantities depending on parameters taken from an empirical probability distribution. Monte Carlo methods are generally of particular usefulness and importance in cases where the calculation of the expectation value is not possible analytically. For parameters which are of interest within avalanche rescue, the existing distributions are empirical data sets for which we mostly do not have analytical formulas.

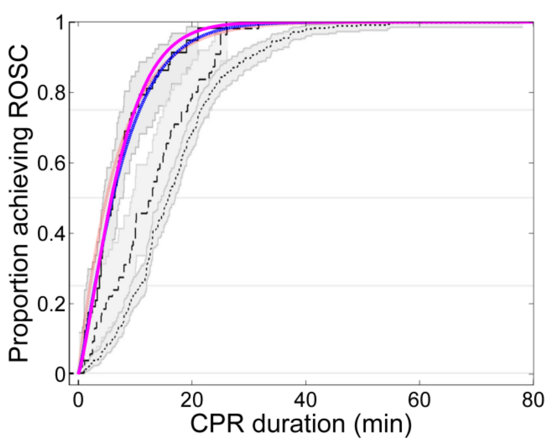

Fig. 2: Probability of achieving return of spontaneous circulation (ROSC) depending on the duration of the cardiopulmonary resuscitation (CPR). The data are taken from Reynolds et al. (2013).

3. RESUSCITATION STRATEGY IN THE CASE OF AN ADDITIONAL BURIED VICTIM

We consider a simple triage – i.e. shortness of resources – scenario for avalanche rescue and assume two avalanche victims and one rescuer. The first victim, from now on referred to as patient 1, is already excavated, normothermic, and shows no vital signs but no obvious lethal injuries, and the second avalanche victim, patient 2, is still buried.

The rescue aim is to save as many lives as possible. As we assume only one rescuer, this person can either engage on resuscitation of patient 1, or search for and excavate patient 2. In other words, we have two competing processes, the increase of survival chance of patient 1 with increasing resuscitation time (Fig. 2), and the decrease of survival chance with increasing burial time for patient 2 (Fig. 3).

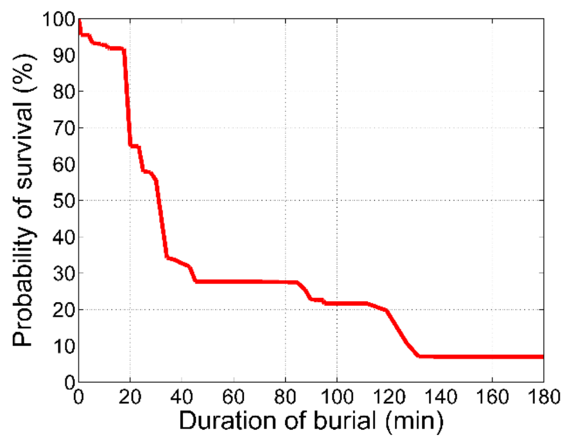

Fig. 3: Survival chance of an avalanche burial as a function of burial time (Brugger et al., 2001).

In the above situation, the avalanche resuscitation algorithm developed by ICAR MedCom (Brugger et al., 2001; Brugger et al., 2013) suggests to perform cardiopulmonary resuscitation (CPR) on patient 1 either until revival or for a maximum of 20 min before proceeding to patient 2. On the other hand, the triage algorithm AvSORT presented by Bogle et al. (2010) recommends not to spend any time on patient 1 who is not breathing despite unobstructed airways, but to continue searching for and excavating patient 2 immediately who is a potential survivor.

Performing resuscitation for a maximum of 20 min strongly favors the survival chances of patient 1 (p1) at the cost of patient 2's survival chances (p2). Proceeding to patient 2 immediately, on the other hand, while optimal for patient 2, minimizes the survival chances of patient 1.

We performed a Monte Carlo simulation to calculate the optimal time for performing CPR on patient 1 before proceeding to patient 2 in order to maximize the sum of the survival chances (p1+p2). We test different times for performing

CPR on patient 1 (t_{CPR}) and simulate the survival chances for each t_{CPR}, ranging from 0 to 20 min in one minute steps.

The initial burial times of patient 1 – which is at the same time assumed to be the starting time of the CPR after the breathing stopped – were chosen as 5,15, and 30 min.

Each simulation consisted of 10,000 runs. We empirically checked the simulation's convergence by varying the number of simulation runs. Once the simulation results did not change anymore with increasing number of runs, we considered the simulation as converged. The simulation steps of our Monte Carlo simulation are described in detail below.

1. The set of random parameters or variables we need for each simulation run are defined as follows:

   i. Search time t_{search} for patient 2. This was taken from a Gaussian distribution.

   ii. Burial depth d_{burial} for patient 2. This parameter is drawn randomly from the burial depths of SLF's avalanche data base.

2. We generate a large number of randomly chosen parameter sets t_{search} and d_{burial}.

3. We deterministically calculate the number of survivors (sum of the survival chances p1+p2) with each set of random parameters. The survival probability of patient 1, p1, is taken from the curve in Figure 2 (Reynolds et al., 2013). The survival probability of patient 2, p2, is calculated with the curve in Figure 3 (Brugger et al., 2001). The duration of burial of patient 2 is the sum of $t_{start} + t_{CPR} + t_{search\&dig}$, where $t_{search\&dig} = t_{search} + d_{burial}/v_{dig}$ and v_{dig} is assumed 5 min per half a meter of burial depth.

4. We calculate the average number of survivors over all simulation runs for each set of the fixed parameters t_{burial} and t_{CPR}.

4. RESULTS AND DISCUSSION

In the sense of «the greatest good for the greatest number» we are interested in maximizing the number of survivors. Note that this quantity is, although the sum of two probabilities, p1 + p2, itself not a probability anymore since it can take values larger than 1. The average number of survivors as a function of resuscitation time t_{CPR} for different initial burial times t_{burial} of patient 1 is shown in Figure 4.

The average number of survivors depends strongly on the time t_{burial}, i.e. the time it takes to start the rescue operation or the time it takes to excavate patient 1 and start performing CPR on him or her.

It can be seen from Figure 4, however, that the optimal strategy for saving as many lives as possible is independent of the initial burial time t_{burial}. There is a pronounced maximum of average number of survivors at a CPR time t_{CPR} of 6 min, for t_{burial} of 15 min and below. If it takes a long time to excavate patient 1, e.g. t_{burial} of 30 min or longer, the maximum flattens, and the average number of survivors drops to roughly 0.33 – which, in this case, is mainly the survival probability of patient 2 – independent of whether CPR is performed, or not.

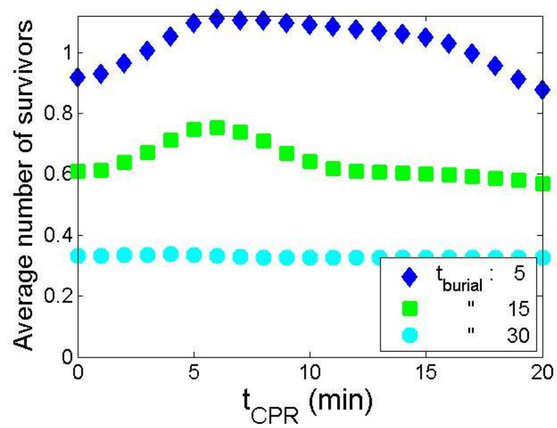

Fig. 4: Average number of survivors over resuscitation time t_{CPR} for initial burial times for patient 1 of 5, 15, and 30 minutes.

It is interesting to note that both the recommendation of Bogle et al. (2010) to proceed to the still buried victim immediately, i.e. t_{CPR} = 0, and the ICAR guidelines, perform CPR until ROSC or death, i.e. t_{CPR} = 20 min, reach similar results. But, according to our simulation, an even better result – i.e. a higher number of average survivors – could be reached by recommending an intermediate t_{CPR} of approximately 6 min. This finding is in accordance to the notion of professional mountain rescuers (personal communication) who feel that either an avalanche victims revives quickly during resuscitation, i.e. after a few heart massages, or not at all.

5. CONCLUSIONS AND OUTLOOK

We conclude that there might be a compromise between the seemingly contradictory guidelines as to whether perform CPR on an avalanche victim in case of additional burials. Whereas the European Resuscitation Council Guidelines (Truhlář et al.,

2015) and the ICAR MedCom guidelines (Brugger et al., 2013) advise to perform CPR for 20 min, Bogle et al. (2010) suggest to proceed to the next burials immediately. Within our simple scenario with two fully buried subjects and only one rescuer we performed a data-based simulation and found a maximum of the average number of survivors in case the rescuer performed CPR on the first patient for approximately 6 min before proceeding to patient 2 who is still buried.

In the future we plan to extend our simulation and use it to calculate more complex avalanche accident settings in order to find a common strategy useful for a wide range of rescue scenarios.

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