Realizing Optimal Chest Compression Fraction During Cardiopulmonary Resuscitation

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***Abstract*— Cardiopulmonary Resuscitation (CPR) is usually preformed in complex situations with multiple parties with a wide range of capabilities. These situations require intermediate pauses for defibrillation, applying advanced airways, and switching CPR administrators. One of the biggest unknowns if chest compression fraction (CCF), which is the optimal fraction of time spent applying compressions. Using the American Heart Association (AHA) guidelines for CPR and rational actor models from game theory, we show the validity of the recommended CCF set by the by the AHA.**

Keywords*— *Cardiopulmonary Resuscitation; CPR; Chest Compression Fraction; Game Theory

I. Introduction

Almost 400,000 cardiac arrests occur outside of a hospital setting each year. Cardiopulmonary Resuscitation (CPR) is a lifesaving intervention and the cornerstone of resuscitation from cardiac arrest [1]. One of the main outcomes desired during CPR is the return of spontaneous circulation (ROSC), or the return of a pulse. The physiological element associated with RSOC is coronary perfusion pressure (CPP). This is the difference between diastolic aortic pressure and the right atrial diastolic pressure. To keep this pressure at a maximum during a cardiac arrest, one has to apply chest compressions. The fraction of time spent administering compressions is called the chest compression fraction (CCF).

In 2015, the American Heart Association (AHA) released an update to CPR guidelines [1]. These guide lines define a system of translational recommendations to apply evidence based findings to increase patient survival. Included in these was the search for optimal CCF. The only study that produced any kind of answer to this question was on that associated higher number of compressions with an increased in ROSC. Using this finding, the AHA says that without an advance airway, it is reasonable to keep CCF above 60% [2]. While having reasonable recommendations is a good starting ground, it is not optimal given the chaotic nature of a cardiac arrest. Using a game theoretic approach will allow policy makers and administrators to not only validate recommendations but perhaps yield more specific advice.

II. Finding Optimal Fractions

A. CPR Score

The AHA likened their recommendation for CCF to that of a car driving down the road; that the number of miles driven is a product of speed and duration of any stops. They relate this to the amount of time compressing to the total benefit applied to RSOC [5]. What they fail to account for is the efficiency of the movement. If with every stroke of the engine is only 80% efficient, you will travel a smaller distance and burn more gas. So rate is not only an important factor, but also how effective the pump is. We can think of this efficiency as a CPR score. We consider a CPR score as a combination of depth of compressions, rate of compressions, and recoil of chest. While these metrics are not specifically defined, we assume the availability of an overall score. With this score we can begin to look at CPR and its effect on CCF.

If a worker has an effective score of 75%, we can assume that his or her output per pump is less than the maximum. In CPR we can relate that to the CPR score. If, for a given session, the average CPR score is 75%, then the amount of pumps required to get to maximum CPP is greater. Anecdotally, around 15 pumps must be given to reach maximum CPP. Using that as a base, a person with a 75% CPR score would need 20 pumps to reach max CPP. This combined with the rate of CPR would give us a time when we can assume that CPP is at a maximum.

- Number of pumps for max CPP = [(1/15)/ .75] = 20 pumps
- 20 pumps * 1.2 seconds/pump = 24 seconds
- 24seconds + 10 seconds per 2 breaths = 34 seconds
- Lower bound of target CCF = 24/34 = 70.59 %

Using these simple assumptions we can already answer a question that the AHA has proposed in its 2015 guidelines; “What is the optimal chest compression fraction?” If we consider the quality of CPR given, the optimal chest compression fraction would not be the same for every person doing CPR. For the example above, the person administrating CPR would not want to do CPR less than 70.59%, otherwise, the CPP would never get to a maximum.

While this algebra is simple and straight forward, a model is needed to realize the interactions between different rational elements present in the situation of CPR and to address the

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other questions raised by the AHA. Game theory deals with these rationalities and has the mechanism support ideal of an excellent candidate.

B. Game Theory

Game theory is the discipline that looks at situations where different players have different actions that result in a specific payoff. Players choose a set of actions called strategies that provide different payoffs. Each player must select these sets in a way that accounts for other players and their actions that might affect the payoffs. A rational player is one that chooses his or her actions in order to maximize their payoff. A Nash equilibrium is a selection of actions in which no other player can choose another action that improves his payoffs. There are two types of strategy, a pure strategy and a mixed strategy. In a pure strategy, a player chooses to play one action %100 of the time. In a mixed strategy, a player assigns different probabilities to the different actions [3]. The mechanisms of game theory can are a good model to express metrics that arise during the administration of CPR.

C. CPR as a Game

To model a cardiac arrest situation using game theory, you start with the players. In this effort, the players were chosen to be the metrics CPP and CCF. You can think of CPP and CCF as players because they both relate to the two actions and have different priorities when it comes to them. For example if the current CCF is %100, we can afford to pause to do some other action. However, if at the same time CPP is only %50, then it would be best to keep administering CPR. The actions set for each player includes 'administer CPR' and 'pause for defibrillation'.

Our players are the CPR metrics CPP and CCF. We can also think of CCF as an administrative metric. It deals with the amount time compressions are applied and the overall team actions. CPP is more related to the worker. In this scenario the EMT doing CPR is most concerned with CPP, because his performance is directly responsible for maintaining CPP. It is reasonable to suggest theses as players because they have the same 'actions' and are effected by the others decisions. If a helper/admin who is concerned with CCF decides to suggest a pause, the worker/EMT will be affected by this (represented by a negative payoff). Fig. 1 is CPR modeled as a game.

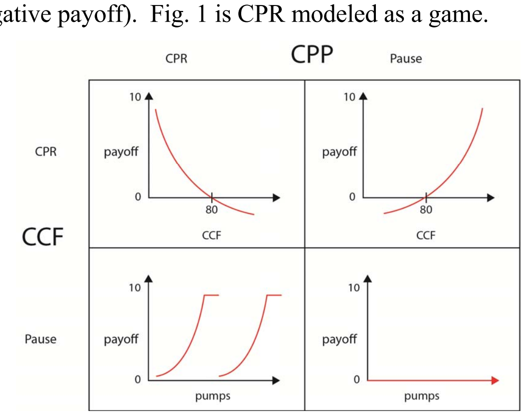

Fig. 1. Utility in CPP vs CCF game

Once we have our payoffs modeled to appropriately reflect AHA's recommendations and the impact of the two players have on each other, we can find an equilibrium. This equilibrium represents the proper CPR/Pause ratio, given a way to measure the CPR score of the worker.

III. Results

Using the above method to calculate an equilibrium using the AHA generated payoff scheme, we have four Nash equilibrium. All of them are dominant strategies (meaning you play one action 100% of the time). This means many things, but one in particular is that the AHA's recommendations do not allow a rational player to use a mixed strategy. If a player is trying to maximize his or her utility, it would be best to not pause or not doing any CPR at all. This is in contrary to a real life situation where a pause would eventually need to be introduced to allow for defibrillation.

IV. Conclusion

In this paper we preset a method of checking the AHA's recommendation for CCF. This includes setting up a game with the appropriate metrics, namely CCF and CPP. Using game theory, we run analysis to find the existence of a mix strategy Nash equilibrium that matches the AHA's recommendations. What we found was that, given the utility models derived from the AHA's recommendations, there exists only pure strategies. In the future, we can derive a utility model (ie the relationship between CPP/CCF and CPR/Pause) that produces a reasonable mixture of actions. Game theory suits this derivation well as it can deal with players that have different yet related priorities and payoffs.

While the analysis did allow for insight to some of the AHA questions, validating with game theory calls for more. More research into the utility relation between CCF and CPP is needed. The next step would be in utility design and recommendations that support target outcomes while including the CPR score.

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