# AN ANALYSIS OF CPR PERFORMANCE, SELF-EFFICACY, AND DELIBERATE FEEDBACK

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**Title**

An Analysis of CPR Performance, Self-efficacy, and Deliberate Feedback

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

**MASTER OF SCIENCE**

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**ABSTRACT**

During sudden cardiac arrest (SCA), prompt initiation of cardiopulmonary resuscitation (CPR) by a healthcare provider or layperson is critical to a patient's odds of survival.[4] The absence of health care providers in athletic settings often leaves coaches as the primary responder in competitive or recreational athletics. The goal of this study was to determine if coaches could provide high-quality CPR. Twenty coaches completed confidence and deliberate feedback questionnaires before and after two sessions of 5 minute compression-only CPR. Data were analyzed to compare confidence pre and post CPR assessment, as well as to determine the relationship between CPR performance, self-efficacy, and deliberate feedback. After receiving feedback on the initial five minutes of compression-only CPR as well as completion of a one-minute bout of CPR with deliberate feedback, a strong, positive relationship between self-efficacy and quality of CPR performance was observed.

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## LIST OF ABBREVIATIONS

ACC ........................................................... American Cardiac College.

AED ........................................................... Automated external defibrillator.

AHA ........................................................... American Heart Association.

ALS ........................................................... Advanced life support.

ARC ........................................................... American Red Cross.

ATC ........................................................... Certified athletic trainer.

BLS ........................................................... Basic life support.

BMI ........................................................... Body mass index.

CAD ........................................................... Coronary artery disease.

CARDIA ...................................................... Coronary artery risk development in adults.

CDC ........................................................... Centers for Disease Control and Prevention.

CPR ........................................................... Cardiopulmonary resuscitation.

CVR ........................................................... Compression/ventilation ratio.

EAP ........................................................... Emergency action plan.

ECG ........................................................... Electrocardiogram.

EMS ........................................................... Emergency medical service.

EMT ........................................................... Emergency medical technician.

HCM ........................................................... Hypertrophic cardiomyopathy.

INL ........................................................... Inter-nipple line.

MBF ........................................................... Myocardial blood flow.

NATA ......................................................... National Athletic Trainers' Association.

NCAA ......................................................... National Collegiate Athletic Association.

NHLBI ........................................................ National Heart, Lung, and Blood Institute.

OHCA ......................................................... Out-of-hospital cardiac arrest.

PEA ............................................................ Pulseless electrical activity.

ROC ............................................................ Resuscitation Outcomes Consortium.

ROSC .......................................................... Return of spontaneous circulation.

RPE ............................................................ Rating of perceived exertion.

SCA ............................................................ Sudden cardiac arrest.

SCD ............................................................ Sudden cardiac death.

VF .............................................................. Ventricular fibrillation.

# 1. INTRODUCTION

## 1.1. Overview of the Problem

Sudden cardiac arrest (SCA) is a leading cause of death in the United States.[4] Although the American Heart Association (AHA) reports prompt provision of cardiopulmonary resuscitation (CPR) can double or triple chances of patient survival during a SCA[4], the survival rate of individuals who experience out-of-hospital cardiac arrest (OHCA) remains at about 10.8% even after emergency medical services (EMS) intervention.[5] Within the athletic population, there is a sudden cardiac death (SCD) incidence ranging from one in 40,000 to one in 80,000.[6] Although a relatively low risk, it is imperative that those who are in direct contact with athletes are able to provide a medical intervention until EMS arrives.

In 2009, only 42% of high schools employed an athletic trainer[7]; therefore, coaches are often the first on the scene of a medical emergency. As a result, it is essential that coaches can perform high-quality CPR. There have been studies[8,9] analyzing physical factors that affect overall CPR performance specific to different healthcare providers, but coaches have not been a population of focus. Despite the fact that coaches are often the first on the scene of a medical emergency, research examining CPR performance in coaches in lacking.

The outcomes of previous research of healthcare workers have concluded that self-efficacy could play a role in overall CPR quality.[10–12] Current CPR training courses may need to be modified to incorporate deliberate feedback since research has suggested that real-time feedback improves acquisition and retention of CPR psychomotor skills.[4,13–15] This research is necessary to determine if integrating confidence-building methods should be incorporated into existing CPR training for coaches.

## 1.2. Statement of Purpose

The primary purpose of this research study was to investigate the relationship between self-efficacy and cardiopulmonary resuscitation (CPR) quality in coaches. The secondary purpose of this study was to determine if deliberate feedback increases coaches' CPR performance and self-efficacy.

## 1.3. Research Questions

Q1: What percentage of coaches achieved satisfactory performance (according to the 2020 AHA CPR Guidelines) on compression rate, depth, and recoil.

Q2: What is the relationship between coaches' self-efficacy and CPR performance?

Q3: To what degree does self-efficacy predict CPR performance?

Q4: To what degree does deliberate feedback effect CPR performance and self-efficacy?

## 1.4. Definitions

Cardiopulmonary resuscitation (CPR): A procedure to support and maintain breathing and circulation for an infant, child, or adult who has stopped breathing (respiratory arrest) and/or whose heart has stopped (cardiac arrest).[4]

Self-efficacy: An individual's confidence to effectively perform a certain skill or behavior regardless of the situation.[10]

Sudden cardiac death (SCD): "Sudden and unexpected death occurring within an hour of the onset of symptoms, or occurring in patients found dead within 24 [hours] of being asymptomatic and presumably due to a cardiac arrhythmia or hemodynamic catastrophe"[16(p7)]

## 1.5. Limitations

Several limitations were present in this study. First, the participants performed CPR on a Resusci Anne QCPR Manikin and in a controlled environment instead of performing CPR on a patient in a clinical setting. Coaches who perform CPR in a clinical setting could have experienced environmental challenges that may lead to changes in self-efficacy or CPR quality. Another limitation was the small population where subjects were recruited. A convenience sample consisting of coaches from North Dakota and Minnesota were recruited for this study. Coaches in other areas of the country may have different rules and regulations regarding CPR/BLS certifications. Additional trainings could lead to differences in CPR performance or confidence. A third limitation is that there were only 20 participants in this study, because of the low number of participants this study was not a great representation of North Dakota and Minnesota as a whole.

## 1.6. Delimitations

The researchers chose to examine the relationship between CPR quality and self-efficacy in a population of coaches due to the absence of ATCs in some settings. The sample of coaches was limited to the Midwest region. Additionally, the researchers chose to have coaches perform two, five-minute bouts of chest compressions, which is less than the national average ambulance response time. Five minutes was chosen to allow participants to complete the study in one session, thereby improving participant retention.

## 1.7. Assumptions

It was assumed that participants answered truthfully on the self-efficacy and deliberate feedback questionnaires. Additionally, the assumption was made that CPR performance on a Resusci Anne QCPR Manikin accurately represented CPR performance in a real-life scenario. Finally, the researchers assumed that each participant gave their maximal effort while performing CPR and completed the session to the best of their ability.

## 1.8. Variables

For research question one, the independent variable were the 2020 AHA CPR guidelines for each component of CPR. The dependent variables were the overall compression rate, depth, and recoil. For research question two, the independent variables were self-efficacy and CPR performance, and the dependent variable was the relationship between self-efficacy and CPR performance. For research question three, the independent variable was self-efficacy and the dependent was CPR performance. For research question four, the independent variable was deliberate feedback and the dependent variables were CPR performance and self-efficacy.

## 1.9. Significance of Study

In the event of a cardiac arrest, every minute of delayed care results in a 7-10% decrease in survival rates.[17] Athletic trainers are equipped to handle such emergencies; however, they are not always present at sporting events, which leaves coaches to serve as the first line of defense in a medical emergency. Therefore, it is essential that coaches know how to perform high-quality CPR. Factors that affect CPR performance of coaches must be identified. The results of previous research studies suggest self-efficacy may be a potential factor contributing to CPR quality,[10,18,19] but after an exhaustive literature search, no studies were found in which the relationship between CPR performance and self-efficacy in coaches. Therefore, research is needed to determine if methods to increase self-efficacy should be incorporated into CPR courses individualized for coaches.

# 2. LITERATURE REVIEW

## 2.1. Sudden Cardiac Death and Sudden Cardiac Arrest

### 2.1.1. Definition

The terms sudden cardiac arrest (SCA) and sudden cardiac death (SCD) are often used interchangeably thus highlighting the need for two distinct definitions.[4,20,21] Due to the lack of standardized definitions of SCD and SCA, it is difficult to determine the exact incidences within the U.S. population.[21] The American Heart Association (AHA) defines SCA as "death from an unexpected circulatory arrest, usually due to a cardiac arrhythmia occurring within an hour of the onset of symptoms, in whom medical intervention (e.g., defibrillation) reverses the event".[4] SCD is defined as " sudden unexpected arrest of presumed cardiac origin in adults >18 years of age".[22] This inconsistency is problematic because SCA and SCD differ significantly. Once a patient goes into SCD they cannot be revived whereas SCA is reversible when proper interventions are initiated.[21] Further research should focus on the development of a clear, universally accepted definition. Creating and implementing standard definitions would increase accurate reporting and help researchers establish the true incidences of SCA/SCD within the U.S. population.

### 2.1.2. Epidemiology

#### *2.1.2.1. General Population*

Organizations like the AHA frequently try to draw conclusions about the incidences of SCD and SCA in the general population from registry data. In 2018, the AHA reported the annual out-of-hospital cardiac arrests (OHCAs) between the years 2014 and 2015. For the study, the AHA relied on statistics from unpublished data collected by the Resuscitation Outcomes Consortium (ROC) between the years 2008 and 2015.[23] The ROC consists of researchers dedicated to studying OHCAs and researching the epidemiologic registry. Breaking down the study's demographics, adults (≥18 years of age) represented 347,322 of the 356,461 OHCAs, and children (<18 years of age) represented 7,037 OHCAs.[23] Because the study is based on unpublished data from the ROC, it is difficult to generalize and analyze the AHA's estimates of SCD and SCA.

Despite the importance of understanding the incidence of SCD and SCA, researchers who attempted a systemic review were only able to locate six relevant articles inferring the true incidence of SCA/SCD.[21] One of the goals of the systematic review was to have a standard and more accurate estimate of SCD and SCA incidence within the U.S. population. The selection criteria included peer-reviewed publications of primary data to estimate the incidence of SCD and SCA. To gather relevant publications, researchers used a data base searching key words such as "death, sudden" OR "death, sudden, cardiac". Researchers limited the results to full text studies of humans age 19+ written in English. This method left researchers with 13,649 abstracts.

As part of the process, researchers excluded reviews, surgical studies, or case reports/editorials/comments/letters, leaving 7,980 viable abstracts.[21] Researchers studied the remaining 7,980 abstracts for relevance and excluded those lacking primary data. After this process, a total of 35 papers remained. Upon completion of further assessment, researchers excluded 29 articles because primary source authors estimated incidence from a subgroup as opposed to full population.[21] In evaluating the six remaining articles, the researchers noted extreme variance. For example, the oldest article was published in 1989, and the most recent was published in 2008. The 19-year range in the publication of the two articles demonstrated the gap in research of standardized definitions of SCD/SCA. Additionally, each study had different methods for estimating the incidence of SCA and SCD.[21] For example, two studies extrapolated data from a national annual incidence of SCA and/or SCD based on small community-based investigations.[21] Another study used a registry for data from eight different sites in the U.S.[21] Finally, the three remaining studies used data from the national level. One of the three studies used data from the national level only reporting data from 40 states, thereby omitting potentially useful data from 10 remaining states.[21]

In the remaining six studies, researchers also found variations in the definitions. Three out of the six articles had time constraints in their SCD case definitions. Additionally, four of the articles included a geographical location as part of their SCD case definition. Further, researchers gave no additional information on what "time constraints" and "geographical location" meant in regards to the study.[21] Two of the articles specifically defined SCD mentioning how death from SCD was "attributable to ischemic or coronary heart disease."[21] A separate study expanded their SCD definition to include patients who died from any cardiac or cardiovascular etiology. Another article included survivors of cardiac arrest for their SCD definition.[21] Additional ways these six studies variated were age population parameters . It should be noted the two most recent studies did not specify age or their criteria. Two of the studies used an age cut-off of ≥25 years; another study had an age cut-off of ≥35 years; and the last study had an age cut off of ≥20 years.[21] The age range variances highlight the perpetual confusion with establishing even a basic incidence SCD rate.

At the conclusion of this systematic review, Kong et al.[21] established two main inferences. First, there is a lack of standardization in the definition of SCD and SCA within the medical community. Second, it is still unclear what the true incidence of SCD and SCA are within the United States population.[21] To estimate and report SCD and SCA in the general population, there needs to be standardized definitions within the medical community of

SCD/SCA. Additionally, set criteria in relation to a standardized definition and larger prospective studies across different regions should be performed.

While researchers are studying SCD and SCA incidences in the general population, they sometimes choose to exclude young adults due the comparative rarity of those events. In 2005, the ROC performed a population-based cohort study from December of 2005 to March of 2007.[20] A total of 11 Canadian and U.S. communities (3 in Canada and 8 in the U.S.) were included in data analysis. The 11 communities consisted of approximately 23.7 million people.

To be included, subjects were evaluated by a participating ROC EMS agency. The patients must have experienced out-of-hospital SCA or SCD with or without pre-hospital care.[20] Subjects were excluded if they had experienced OHCA as a consequence of blunt, penetrating, or burn trauma. Researchers included subjects who experienced OHCA due to mechanical suffocation and drowning. Data collected included: subject demographics, event characteristics of etiology, scene time, airway management, drug therapy, initial recorded cardiac rhythm, and bystander CPR. Scene time was defined as “the interval from EMS arrival until the transporting vehicle started moving”.[20] Initial cardiac rhythm was defined as “the first rhythm obtained within five minutes of pad or electrode placement and before drug administration” and was obtained from patient care records.

The researchers used an age parameter of <20 years to divide patients *a prori* into one of three groups: infants (<1 year), children (1-11 years), and adolescents (12-19).[20] Additionally, researchers queried the ROC database from December 1, 2005 through March 31, 2007 for patients ≥ 20 years for data elements including: scene time, percentage of those treated by EMS, missing initial cardiac rhythm, and survival to hospital discharge.[20] The main outcome measure used by researchers was survival to hospital discharge.

For calculation of data, descriptive statistics were reported as mean (SD). The researchers conducted *t*-tests for comparison of continuous variables between two groups and used ANOVA for comparison across three groups or more. Additionally, multiple logistic regressions were conducted to model the relationship between survival and potential predictors of outcome.[20] Age, witnessed arrest, bystander CPR, EMS scene time (<10 minutes versus ≥ 10 minutes), airway management, and attempts at vascular access were all used as potential predictors.[20] EMS providers took an estimated minimum time of 10 minutes to arrive at the patient's side, assess the patient, provide initial resuscitation efforts, and transfer the patient to the transporting vehicle. Finally, the researchers conducted post hoc analyses of scene time among the combined pediatric age groups versus adult scene time.[20]

To obtain final estimates, incidence rates per 100,000 person-years were recorded for a 12-month period (March 1, 2006 to February 28, 2007) (see table 1). Ultimately, only 10 sites were used due to incomplete data at one site. At each site, sex-specific and age category rates were calculated and standardized. These rates were weighted by the site population and then averaged to obtain overall rates. The researchers found there was a higher prevalence of OHCA in infants.[20]

**Table 1.** Patient Characteristics[a]

| Characteristic | Infants | Children | Adolescents |
|---|---|---|---|
| Total number of patients | 277 | 154 | 193 |
| Age – Mean (SD) | 0.3 (0.2) | 4.2 (3.0) | 16.4 (2.1) |
| Incidence/100,000 person-years<br>(95% CI) | 72.71<br>(62.02, 83.39) | 3.73<br>(3.02, 4.43) | 6.37<br>(5.30, 7.44) |

[a]adapted from Atkins et al.[20]

The researchers noted several factors contributing to a higher occurrence for infants. They have attributed elements such as age populations, race, and rural versus urban environment as aspects that influenced higher incidence rates.[20] Additionally, having higher rates depend on whether researchers decide to use traumatic cardiac arrests for the inclusion criteria. Traumatic cardiac arrests account for 30% of pediatric arrests.[20] Use of the ROC database resulted in a more diverse spectrum of data compared to other studies which used a single site.

***2.1.2.2. Athletic Population***

Due to often elevated public attention, the incidence of SCD and SCA are thought to be higher in athletes than the general population; however, this is misconception. The misconception is often due to media coverage exaggerating the true incidence of SCD and SCA.[24] The actual number of sudden deaths during sports competition is low in the United States. Data extrapolated from Atkins et al.[20] suggested an incidence of 3,000 and 5,000 sudden cardiac arrests per year between ages one and 19 years in the U.S. population. Of those sudden cardiac arrests, an estimated 100 to 150 occurred in competitive athletes.[20] This estimation inferred only a small fraction of SCDs in youth occur during competitive athletics. The Centers for Disease Control and Prevention (CDC) estimated similar accounts of the average number of deaths in young, competitive athletes congruent with the Atkins et al. study.[24] Even though the CDC published low estimation of SCD in young athletes, there is conflicting evidence from a study conducted by Corrado et al.[2]

There is only one published study supporting the idea of increased SCD incidence in athletes when compared to nonathletes.[2] The study was a 21-year prospective cohort in Italy including about 1,400,000 (age 12-35) young adults. Out of these 1,400,000 young adults, approximately 113,000 were competitive athletes.[2] At the end of the observation period, the researchers found 259 cases of sudden death were from cardiac pathology. Fifty-one of these deaths were in athletes and 208 were non-athletes.[2] The overall SCD incidence in the athletic population was 2.1 per 100,000 persons per year for athletes and 0.7 per 100,000 person per year for non-athletes.[2] Although these findings suggest athletes have a higher rate of SCD compared to non-athletes, other evidence does not support this notion.[1,24]

The results of the aforementioned study[2] conflict with other large-scale studies completed in the United States and Denmark. In a retrospective study, 27 years of registry data within the United States was examined. The researchers estimated an SCD incidence of approximately 0.6 per 100,000 persons per year[1]; however, multiple key limitations were identified. When this paper was published (2009), there was no mandatory reporting system for SCD in young athletes within the United States. It is not presumptuous to infer the lack of mandatory reporting could have led to underreporting and an overall lower estimate of SCD. During the last six years of this study, reported SCD rates increased within the athletic community. Researchers noted this increased reporting could have been from improved methods of reportage and surveillance. If these methods had been implemented for the entire duration of the 27-year study, there likely would have been higher incidences of SCD.[1]

A six-year study conducted in Denmark tracked the number of competitive athletes between the ages of 12 and 35 who suffered from SCD.[24] The researchers reported a rate of 1.21 per 100,000 athletes person-years compared to a rate of 3.76 per 100,000 person-years within the general population.[24] Corrado et al.[2] acknowledged other researchers[25] reported rates much lower than their original report, and they attributed these discrepancies to the difference in design used in other studies. An example of this was a study conducted by Maron et al.[25] who estimated the prevalence of cardiovascular SCD in competitive high school athletes (age 13 to 19) in the state of Minnesota. Researchers found the prevalence to be 0.35 in 100,000 sports participants for high school males and 0.46 in 100,000 participants per year for all high school students.[25] The results suggest that different sports' levels of intensity affected the incidence of SCD. The research on the incidence of SCD in the athletic population is just as inconsistent as the incidence of SCD in other populations. Therefore, there is a need for multiple, larger-scale studies incorporating standardized methods of reporting.

Over the course of a nine-year study, researchers attempted to estimate the true incidence and causes of SCA/SCD at the collegiate level.[26] Researchers wanted to investigate NCAA collegiate athletes because the frequency of cardiovascular deaths within the collegiate population influences pre-participation screening strategies.[26] The results of a non-forensic based analysis demonstrated a relatively high occurrence of SCA/SCD within the athletic population (2.3/100,000 athlete-years).[26] This rate was elevated when compared to previously discussed studies[2,24] and caused concern within the athletic community. Due to the lack of consistent findings related to SCA/SCD rates,[2,24] researchers set out to analyze their own forensic database to estimate the true causes and incidences, thereby easing concerns over sport participation.[26]

The data were primarily collected from The U.S. National Registry of Sudden Death in Athletes and the National Collegiate Athletics Association's (NCAA) Sport Sponsorship and Participation Rates Report.[26] The researchers collected pertinent clinical data, circumstances of death, and an autopsy report. For information regarding athlete death in the NCAA, researchers acquired basic demographic information such as race/ethnicity and sex from the NCAA Student-Athlete Ethnicity Report.[26] Between the two sources, a total of 182 deaths were recorded between 2002-2011.[26] Researchers compared mortality rates from the NCAA registry to available data regarding cardiovascular causes, drugs, and suicide within the general population.[26] Additionally, mortality rates were assessed and compared across similar population and subpopulation groups.[26]

Mortality within the athletic population was caused by a variety of circumstances and disease.[26] Out of the 182 deaths, 116 were due to causes other than cardiovascular disease, including suicide (n= 31), drugs (n= 21), and trauma (n= 11).[26] The remaining 64 athletes, cardiovascular (CV) abnormality was the most likely cause of death (confirmed CV n=47, presumed CV n= 17). Football and men's basketball were the most common sports associated with cardiovascular deaths. In 47 of the 64 deaths, a post-mortem examination revealed a cardiovascular abnormality as the probable cause of death.[26] For deaths confirmed a cardiovascular abnormality, hypertrophic cardiomyopathy (HCM) was the most common cause of death. These results support other research[1] that HCM is the most common cause of CV death in athletes.[26]

The researchers identified certain ethnicities had an increased risk of CV-related deaths. Within the data set, African American males had a higher risk of cardiovascular-related death when compared to their white, male counterparts (3.8 vs 0.7/100,000 athlete participation-years; $p < .0001$).[26] However, the death rate for African American male athletes was similar to the general population of African American males in the same age group. Although white, male collegiate athletes have lower rates of cardiovascular disease compared to the general population, cardiovascular risks remain a concern in sports for all who participate.

Over the nine-year span, an average of 4,052,236 athletes competed in the NCAA in a single year.[26] Researchers calculated the 47 confirmed cardiovascular cases and equated it to 1.2/100,000 deaths per athlete participation-years. When combined with the 17 presumed cases, chances of death increased to 1.6/100,000 athlete participation-years from cardiovascular pathologies. Although cardiovascular diseases accounted for a majority of deaths, suicide and drugs combined to a total of 1.5/100,000 athlete participation-years.[26] The data presented by

Maron et al.[26] was in direct conflict with the previously mentioned death rate from the non-forensic based analysis of 2.3/100,000. These findings suggest the death rate of athletes related to SCA/SCD might not be as high as the media portrays it to be.

The results from this study correspond with previously mentioned studies,[1,20,24] suggesting athletes do not have a higher risk than the general population for cardiovascular-related deaths. However, having reliable pre-participation 12-lead ECGs can help mitigate cardiac-related deaths.[26] From the 47 deaths, researchers presumed 28 of them would have been identified or suspected if an ECG had been used in pre-participation screening.[26] Thus, it is possible 60% of cardiac-related deaths in athletics could have been prevented with the utilization of pre-participation ECGs.

Being able to properly screen athletes who are at higher risk for cardiovascular emergencies is an important step in helping minimize the number of athletes who succumb to an SCA/SCD related death. Since African American males are at a higher risk than their white male counterparts,[26] special attention should be given to African American males so they can be properly screened for cardiovascular pathologies. Proper pre-participation screening should encompass a thorough family history and a 12-lead ECGs to mitigate preventable deaths.

In addition to the lack of standardized SCA/SCD definitions, there appears to be a lack of strategic and specific reporting for athlete deaths.[27] Data from the aforementioned studies[1,2,24,26] were collected from different registries and reports. The lack of consistent reporting could have led to discrepancies in results, thereby making it difficult to make inferences for the entire athletic population.

To make it easier to determine the true incidence of SCD, Solberg et al.[27] suggested a dependable method to report SCD within the athletic population.[27] One of the primary recommendations made by researchers was to standardize definitions for "athlete" and "sudden." The word "sudden" has ambiguity in its meaning depending on the definition. When the definition of SCD included one hour from onset of symptoms, the proportions of all deaths were 13%. When the definition for SCD included a 24-hour time frame, the proportion of death increased to 19%.[27] The lack of consistent definitions increases the risk of inconsistency in raw data. Having set definitions for this particular subset is important because it can help future researchers, organizations, and institutions develop and implement strategies to mitigate these tragedies.[27]

In addition to standardized definitions, researchers also suggested a comprehensive enrollment of cases.[27] Having organized registries at the regional and national levels that collaborate with emergency responders to report any cases of SCD can help estimate incidences. Included in the reports should be the victim's age, gender, ethnicity, sporting discipline, and intensity of the exercise. These demographics are important because they can help further dictate which demographics require future research. Once a death is reported, the researchers recommended an autopsy should be conducted.[27] In addition to the autopsy, it is proposed a toxicology report be completed. Over time there has been evidence linking doping and illicit drugs to SCD in the athletic population.[27] Furthermore, the researchers recommended infrastructure of the facility be noted. Because sports can be practiced virtually anywhere, special consideration should be given on how to navigate medical emergencies where sports are played. Since the way organizations implement their emergency action plans (EAPs) for their venues can significantly impact outcomes for SCD, having succinct and efficient plans play a vital role in how SCA/SCD emergencies are handled.[27]

Implementing standardized definitions, a consistent registry, and collecting demographics are all strategies that may help determine the true incidences of SCA/SCD in the athletic population. The data collected from these guidelines can also assist medical professionals determine which groups are at higher risk and require further evaluation and cardiovascular testing. These action steps are capable of reducing death and dictate future SCA/SCD research.

**2.1.3. Causes**

***2.1.3.1. Structural Diseases***

Coronary artery disease (CAD) is a structural cause of SCD and SCA with approximately 80% of SCD being attributed to CAD.[28] The main cause of CAD is a condition known as atherosclerosis characterized by an accumulation of plaque within the vessels.[29] If too much plaque builds within the arteries, it can obstruct blood flow in the vessel.[29] Additionally, plaque can rupture, resulting in platelets forming vessel-occluding blood clots in the area.[29] This vessel occlusion can result in myocardial infarction, which can eventually cause SCA and SCD if left untreated.[29] Myocardial infarction is characterized by the death of cardiac myocytes caused by ischemia, which results in a perfusion imbalance between supply and demand.[30] Thus, recognition and early intervention of CAD is imperative to the prevention of myocardial infarction.[29]

Although annual numbers of death vary, hypertrophic cardiomyopathy (HCM) is another common structural cause of SCD.[31] HCM is depicted by left ventricular hypertrophy in the absence of abnormal loading such as exercise training or hypertension.[31] In a study by Maron et al.,[32] researchers evaluated Coronary Artery Risk Development in Adults (CARDIA).[32] The purpose of this study was to estimate the prevalence of HCM in young adults. The National

Heart, Lung, and Blood Institute (NHLBI) established the large-scale, prospective CARDIA study to investigate how lifestyle and other factors play a role in coronary artery disease.[32]

The original study included 10,143 participants; however, the researchers chose to exclude participants outside the age range of 18-30. This resulted in a sample of 5,115 participants.[32] Participants were randomly contacted from four diverse geographical urban field centers: Birmingham, Alabama; Chicago, Illinois; Minneapolis, Minnesota; and the Kaiser Permanente Medical Care program in Oakland, California. The age range set by researchers was stratified to achieve approximately equal number of blacks and whites as well as male and female subjects.[32]

At the start of the study, blood pressure, height, weight, total plasma cholesterol determination, exercise tests, and an electrocardiogram (ECG) were conducted on participants. The same examination was repeated five years later when participants were 25 to 35 years of age.[32] Subjects were excluded from the study if they were physically unable to complete the three-hour examination (which included the exercise test) because of systemic or cardiac symptoms presenting a functional limitation.[32] Of the 4,243 ECG's obtained five years later, 4,111 (97%) had satisfactory echocardiographic studies permitting reliable assessment of left ventricular wall thickness.[32] For participants to be diagnosed with HCM, they had to have a left ventricular wall thickness of ≥15 mm measured via ECG.[32] About 0.2% (95% CI, 0.07% to 0.35%) of the participants were diagnosed with HCM. This equates to about 1 in 500 persons per year being estimated to have HCM.[32] Although this was one of the first studies to determine the rate of HCM based on prospective data, a limitation was the attrition of participants from initial recruitment to follow-up analysis.

In contrast, in a nine-year prospective study of the entire population of Olmsted County, Minnesota, researchers reported HCM occurred at a rate of only 0.02%.[33] Investigators were able to conduct a population-based epidemiologic research study in Olmsted County because medical care is delivered by a small handful of the same health care providers at the infamous Mayo Clinic.[33] The researchers were able to use indexed medical records from the Mayo Clinic to identify Olmsted county residents who were diagnosed with HCM within the 10-year period. A total of 3,250 potential cases were screened with 69 cases being accepted for the study. A total of 46 for were diagnosed with dilated cardiomyopathy and 21 with HCM. When indexing patients' medical records, researchers analyzed for one of three codes from the International Classification of Diseases, Eight Revision (H-ICDA). Code 425, which specifically relates to cardiomyopathies; Code 427, which pertains to heart failure; and Code 429, denotes a category of "ill-defined heart disease".[33] Additionally, subjects needed to have established residency in Olmsted County for at least one year prior to diagnosis. Of the 21 cases with HCM, 18 participants were diagnosed during their lifetime and three were diagnosed at autopsy. All of the subjects had a thickened interventricular septum (median, 17 mm; range, 13-23 mm).[33] Patients were excluded from this cohort if they had left ventricular hypertrophy secondary to known causes, such as systemic hypertension or aortic stenosis.

The methodology likely resulted in an underestimation of HCM. As medical records were only used if they had sought medical treatment from a local hospital and then were diagnosed with HCM instead of trying to include as much as the population as possible.[33] To gain better understanding of the incidence of HCM in the general population, further prospective-cohort research studies should be conducted.

In young athletes, HCM is often the most common cause of SCD.[1] Researchers analyzed 27 years (1980-2006) of data from the US National Registry of Sudden Death in Athletes (USNRSDA) to determine the number of sudden deaths and their underlying causes.[1] The Minneapolis Heart Institute Foundation formed the registry to gather and analyze data on deaths of young athletes during competitive sport.[1] To qualify, two inclusion criteria had to be met. First, the athlete had to be involved in an organized individual or team sport regularly competing with others. Second, sudden death of the athlete must have occurred at ≤ 39 years of age.[1] Subjects were excluded from the study if a specific cause of death was not determined by lack of autopsy, access to postmortem and/or clinical findings were restricted by confidentiality and privacy obstacles, or the autopsy report was available but histopathologic findings were ambiguous and insufficient.[1] Researchers included 85 athletes who survived cardiac arrest by defibrillation or CPR. For the purpose of the study, they were considered to have experienced sudden death.

Researchers used the records of multiple organizations including the National Federation of State High School Associations, National Collegiate Athletic Association, and the National Association of Intercollegiate Athletics. Researchers conducted $X^2$ or Fisher's tests to compare proportions. Continuous variables were assessed with unpaired *t*-test or a Mann-Whitney rank sum test. A Poisson regression analysis with log link and likelihood ratio tests were conducted to assess trends over time. To calculate the incidence of sudden deaths, the average of the events occurred from 2001 to 2006 was divided by the estimated number of participants in all competitive sports.

Of the 1,866 total deaths, 1,049 (56%) were diagnosed as cardiac in nature.[1] HCM was reported to be the most common occurring cause, which suggests 251 (36%) of the deaths had a maximum left ventricular wall thickness of 23±5 mm.[1] Researchers noted from 1994 to 2006 (1290), incidences were significantly higher than from 1980 to 1993 (576, $p < .001$). Additionally, the proportion of all deaths reported in female athletes increased over time ($P < .0001$; 95% CI 1.4 to 2.3). The results from this study support the previous,[32] thus suggesting HCM is a leading cause of death within athletic population.

In 2015, a similar retrospective study was conducted by the National Collegiate Athletic Association (NCAA). The population included 514 student athlete deaths over a 12-year period from 2003-2014. Data were gathered from the Parent Heart Watch database, NCAA insurance claims, and the NCAA Resolutions List.[34] The Parent Heart Watch is a national nonprofit organization dedicating itself to the prevention and awareness of sudden cardiac arrest and SCD among athletes.[34] The NCAA insurance claims covers NCAA athletes in case of a catastrophic injury, providing a death benefit of $25,000 for athletes who pass away during competition, practice, conditioning, or any other organized event supervised by the institution.[34] The NCAA Resolutions List is compiled annually to honor student-athletes who have died of any cause. The list is generated from monitoring national media and by institutions who self-report student-athlete deaths.[34] During the 12 year period, 15% of the deaths were attributed to SCD. Researchers were able to review 69 autopsy reports and found the most common discovery in victims of SCD was an autopsy negative sudden unexplained death (AN-SUD). Victims of SCD whose autopsies were analyzed indicate 25% of them had AN-SUD while only 8% had HCM.[34] These findings contradict those of previously described studies[1,32] with rates of HCM were that much lower than other reports.

Several factors could be attributed to discrepancies in the 2015 NCAA study and the study from 2009.[1,34] The USNRSDA supplied data for the 2009 study, which can be found at the

HCM Center at the Minneapolis Heart Institute Foundation.[34] This could have led to ascertainment bias while collecting data. Additionally, different criterion were used for diagnosis of HCM.[1,34] Having different diagnostic definitions could have led to one study excluding certain cases while the other study including the data. Future studies should use a standardized diagnostic definition of HCM and SCD to examine causes of SCD and other structural diseases of the heart.

#### *2.1.3.2. Electrical Abnormalities*

Not only do structural abnormalities of the heart contribute to SCD, but electrical abnormalities also play a role. Ventricular fibrillation (VF) and pulseless electrical activity (PEA) are two of the most common cardiac arrhythmias that cause SCD.[28] VF is a disordered electrical activity in the lower chambers of the heart leading to the ventricles quivering instead of contracting. When this happens, SCA could occur because there is no contraction. The lack of contraction indicates there is a lack of blood being pumped through the heart. When a heart undergoes PEA, if it is analyzed via a 12-lead ECG, it will appear normal except it will not produce a pulse. It is essential health care providers can properly read 12-lead ECGs and are confident in feeling for a pulse to decrease the possibility of SCA.[35]

The incidence of PEA and VF in SCD victims has changed over the past decades. An analysis of emergency medical service (EMS) in the Seattle area found a decrease of 56% in VF from 1980 and 2000.[36] This information yields similar results where researchers analyzed 17 years of hospital data from Goeteborg, Sweden, and found an increase in PEA from 6% to 26% but a 34% decrease in prevalence of VF.[37] The shift in prevalence of both VF and PEA may be due to different factors. PEA can be attributed to non-cardiac conditions while VF is normally associated with coronary disease.[38] The reduction of CAD may contribute to the reduction of

VF.[38] VF has received more attention than PEA. The most recent large-scale study on PEA was conducted in the 1940s.[38] The lack of large-scale studies make it clear PEA needs to be researched and examined more fully to understand its prevalence and how to combat it as a common electrical cause of SCD.

Within the athletic population, ECGs are popular screening tools used by physicians to monitor conduction disturbances and identify underlying cardiac disorders.[39] In 2012, an international group consisting of sport cardiologists and sports medicine professionals met in Seattle, Washington. The goal of their meeting was to define contemporary standards for the interpretation of ECGs within the athletic population.[39] Additionally, another goal of the meeting was to assist physicians on what abnormal findings look like and what dictates further evaluation for conditions predisposing athletes to SCD.[39]

The health professionals who met decided abnormal ECG findings were suggestive of an ion channel or conduction disorder associated with SCD. Some of the common disorders presented in athletes included: congenital long and short QT syndromes, catecholaminergic polymorphic ventricular tachycardia, Brugada Syndrome, ventricular pre-excitation, supraventricular tachycardias, atrioventricular blocks and premature ventricular contractions. It was determined if any of these electrical abnormalities were to be found on athlete's ECG, the athlete should be screened for additional irregularities.

## 2.2. Cardiopulmonary Resuscitation

### 2.2.1. History

It is estimated 350,000 people experience cardiac arrest every year.[40] Early intervention, including administration of cardiopulmonary resuscitation (CPR), is key for improving chances of survival.[40] CPR is a relatively new term which has only been around for approximately 50 years.[40] Present day CPR practices are drastically different from the way CPR was performed at its inception. The first account of CPR administration from which protocols were adapted dates back to the Han Dynasty (202 BC-220 AD).[41] The protocol required three rescuers and included a combination of chest compressions and limb massage.[41] This initial use of CPR led to the development of current practices and guidelines over time.

As practices developed, variations of chest compressions were added to increase circulation and survival rates of CPR. In 1966, the American Heart Association (AHA) enacted CPR guidelines in addition to other advanced life support tools such as defibrillators, which resulted in increased survival rates.[42] Interestingly, various parameters of CPR such as artificial ventilation and chest compressions can be dated back to the 19th century.

CPR administration is not limited to hospital and medical settings. As cardiac disease and complications from those diseases continue to increase in the United States, bystander intervention is critical in the acute care of cardiac arrest. In fact, an estimated 330,000 out of 494,382 individuals who died from coronary artery disease died before they could get to the hospital or shortly after they were admitted.[43] Thus, initiating CPR in the pre-hospital setting is crucial for improving survival rates of cardiac emergencies.

In 1991, the AHA published the "Chain of Survival," to prevent early cardiac death. The chain of survival consists of four links; if initiated properly and timely, could increase the chance of survival of a cardiac event. The four links include: early access, early CPR, early defibrillation, and early advanced cardiac life support.[43] Early intervention by bystanders is proven to more than double the chance of survival for cardiac arrest victims; however, only 27% of cardiac arrest victims receive CPR prior to the arrival of EMS in the United States.[43]

In an effort to determine bystander willingness to perform CPR and causes for hesitation to initiate care, Locke et al.[44] conducted a survey-based investigation. Researchers sent out 3,420 questionnaires to individuals who were on a mailing list for the University Heart Center at the University of Arizona College of Medicine in Tucson, Arizona. The questionnaire consisted of four different scenarios where the participant was the only bystander at the scene with an individual who collapsed. For each scenario, the individual was asked on a four-point, Likert-type scale how likely they were to initiate CPR (1 indicating would definitely perform and 4 indicating would definitely not perform.).[44] A total of 975 questionnaires were returned. Out of those 975, 80% were members of the public and 20% were health care providers.

The researchers conducted a repeated-measures analysis of variance ANOVA to examine the participants' willingness to perform CPR.[44] Because there was a relationship between delivering ventilations and concerns over disease transmission, a Pearson product-moment correlation coefficient and t-distribution were conducted. Scheffe tests were conducted to assess differences between groups means. A Chi-squared analyses were conducted to examine relationships between categorical variables such as previous CPR training/experience and impact on CPR technique.

The aforementioned analyses revealed only 18% of respondents had taken a CPR class within the last two years. When asked about comfort delivering mouth-to-mouth ventilations, 82% of the participants answered they were either "very concerned" or "moderately concerned" about disease transmission. Participants who had never taken a CPR course provided some of the following reasons: no opportunity (50.1%), not having time (15.6%), unsure if I could learn (15.1%), and would be afraid to use (7.9%). Women were more likely to say they were afraid (4% vs 13% and $p = .004$), and men were more likely to say they had no opportunity (57% vs

41% and p = .044). Although some participants reported they would initiate CPR, there are still barriers limiting bystanders from beginning early CPR such as the fear of disease transmission and fear of performing CPR improperly.

#### *2.2.1.1. Origin of Artificial Ventilation*

Artificial ventilation is one of the core components of modern CPR. It has evolved through different techniques over the course of its development. In the 16th century, Swiss physician and alchemist Paracelsus used a pair of bellows, a device designed to supply a fire with a strong burst of air to ventilate drowning victims.[45] In the 19th century, mechanical methods of artificial ventilation were favored. The techniques were similar to modern chest compressions to produce expiration and recoil inspiration; tidal volumes were produced from this method. [40] These variations on mechanical ventilation via chest pressure were not practiced until the mid-1900's.[46] In research experiments led by James Elam,[47] Archer Gordon,[48] and Peter Safar,[49–51] evidence was found proving expired air, or positive-pressure ventilations provided sufficient oxygen for successful artificial ventilation. Additionally, the aforementioned researchers discovered positioning a patient in a prone position during ventilations, which at the time was a common practice,[46] compromised the airway.[49] Safar et al.[50] advocated for manually extending a patient's neck and bringing their jaw forward to maintain a patent airway. Currently, these techniques are referred to as "head-tilt, chin-lift" and "jaw-thrust" maneuvers. The practice of positive-pressure ventilations and keeping a patient supine during resuscitation efforts became standard in emergency medicine.[40,46]

#### *2.2.1.2. Origin of Chest Compressions*

Chest compressions, another key component of modern CPR, first emerged in the 18th century but did not reach its contemporary technique until the mid-1990's.[40] The primary goal of contemporary chest compressions is to manually generate blood flow to the heart and brain;[52] however, in its earliest form, chest compressions were intended to assist with breathing.[40] The early methods of chest compressions involved draping an unresponsive individual prone over a barrel or horse. While the barrel rolled or the horse trotted, the individual's chest would be compressed.[46] The first known compressions to stimulate blood flow were performed on a heart through a surgical opening in the thorax. Originally discovered in 1874 when German physiologist Moritz Schiff noted carotid pulsations occurred in a dog every time he squeezed its heart.[40] The term "open-chest cardiac massage" was developed from Schiff's technique even though it was not used frequently in practice until the early 1900's.[45] In the 20th century, Kristian Igelsurd, performed the first successful open-chest cardiac massage on a human patient in 1901, thereby launching the standardization of using open-chest cardiac massage for sudden cardiac arrest (SCA) resuscitation.[46]

In 1958, electrophysiologist William Kouwenhoven, while researching manual defibrillation on canines, noted a rise in arterial pressure each time defibrillation paddles were pushed onto a dog's chest.[46] Subsequently, Kouwenhoven et al.[53] performed closed-cardiac massage on 20 hospitalized SCA victims and was able to successfully resuscitate 14. This breakthrough suggested external compression was a feasible alternative to open-chest compressions. Due to the ease and simplicity of external chest compressions, the technique soon became the standard of care in emergency resuscitation.[45]

#### *2.2.1.3. Origin of Modern CPR Guidelines*

After the landmark research conducted in the late 1950's,[51,53] the foundations for modern CPR were established. In 1966, the AHA sponsored the first official conference on CPR. This conference resulted in the development of standards regarding what techniques to use and how to use them effectively.[46] These newly established guidelines encouraged members of the conference to teach trained medical professionals but not to teach the general public. The AHA feared untrained laypersons attempting to perform CPR might cause further harm to SCA victims.[40] In 1970, in King County, Washington, a group of researchers and physicians created and conducted an ambitious emergency response project. The project entailed teaching approximately 100,000 citizens proper CPR technique.[36] At the time of this impressive project, teaching citizens CPR contradicted current AHA CPR guidelines.

In an attempt to reduce the mortalities during medical emergencies, researchers investigated if the inclusion of paramedic services reduced mortality of OHCA.[54] During one year (April 1976 – August 1977), researchers collected the number and details of SCA cases in King County, Washington, hospitals and emergency agencies. Researchers also tracked factors such as time from collapse to initiation of CPR, time from collapse to definitive care, and victims' outcomes.[54] In the study, only non-traumatic OHCAs were considered; all ages were included; and, a valid case was defined as "a patient with cardiac arrest with a pulseless condition (confirmed by an EMT or paramedic) for whom CPR was initiated."[54] The researchers accumulated 604 cases of OHCA.

After data were collected, an independent Pearson's Chi-square test was conducted to determine whether any of the variables were significantly related.[54] The researchers found a short time to initiate CPR ($p < .01$), bystander initiated CPR ($p < .01$), and short time to definitive care ($p < .01$) were all significantly associated with positive patient outcomes.[54] Of the three statistically significant variables, researchers determined shortened time to CPR initiation was the most important factor.[54] Researchers used the term "bystander" to describe anyone who was present at the scene of an SCA.[54] If a bystander initiated CPR, it was likely the time between the start of the SCA and start of CPR decreased.[54] Researchers concluded bystander-initiated CPR had a positive association with patient outcomes and reflected the significance of early CPR initiation.[54] This study provided enough evidence exhibiting the importance of teaching CPR to the general population. As a result of this study,[54] the AHA formally approved the teaching of CPR to laypersons when they revised their guidelines in 1973 and began to investigate other aspects of CPR techniques.[40]

#### ***2.2.1.4. CPR History 2000-2004***

Throughout time, considerations and recommendations for administration of compressions and ventilations rates were analyzed and adjusted. Historically, the recommendation ratio between compressions and ventilations were set at 5:1.[55] This ratio meant for every five compressions given, one ventilation was administered. In 2000, the American Heart Association (AHA) released their updated guidelines. These recommendations adjusted the compression to ventilation ratio from the previous 5:1 and increased it to a ratio of 15:2.[55] The AHA decided to increase the compression to ventilation ratio because researchers observed an increase in positive patient outcomes with a greater number of compressions.

To test and validate their new recommendations, researchers observed 17 paramedic students who recently completed a 30-hour certification course.[56] The paramedics were paired for two different protocols. For each protocol, one participant was assigned as rescuer one and the other as rescuer two. After each scenario, they would switch roles for a total of four completed scenarios.[56] For each scenario, the pair was instructed to perform CPR until the completion of intubation, intravenous medication administration, and an application of a shock from a defibrillator. Data were collected with a computer system while CPR was performed on the Ambu Mega Code Trainer.[56] In addition to the previously described dependent variables, participants were recorded on two different video camera for additional data collection.

The researchers discovered significantly less CPR cycles were required when performing the 15:2 method compared to the 5:1 method (5:1 = 3.0 cycles, 15:2 = 1.75 cycles, p = .000).[56] This decrease in the number of cycles allowed for less time overall in giving ventilations which in turn increased the number of compressions given to the victim. Although researchers noted no significant differences in quality of CPR between the two methods, they did note a decreased time interval between the start of compressions and the transition to ventricular defibrillation in the 15:2 group (5:1 = 125 ± 15 seconds, 15:2 = 90 ± 15 seconds, p = .0001).[56] Through these results, researchers determined the 15:2 ratio was an effective and time-saving method of performing CPR. This was the only human study cited by the AHA for their new 15:2 recommendation.

The AHA also mentioned a study involving pigs as a model. In this study,[57] researchers analyzed 10 pigs who received compression-only CPR and 10 pigs who received the AHA recommended 15:2 compression-to-ventilation ratio. From the results, researchers found no significant differences between the two different groups for survival rates.[57] With limited research supporting the ratio change from 5:1 to 15:2 compression-to-ventilations, further research was needed to advance the idea of increased compression-to-ventilation ratios to maximize survival rates of patients who experience cardiac arrest.

#### *2.2.1.5. CPR History 2005-2009*

The AHA published new guidelines supporting the change of several aspects of CPR in 2005. Compressions were to be performed at the rate of at least 100 compressions per minute with minimal interruptions for pulse checks or ventilations.[58] In the new 2005 guidelines, the

AHA altered some wording from their 2000 guidelines. In regards to chest compression rate, they replaced the word "approximately" with "at least".[58] This change in wording established a lower rate at which compressions should be performed. To improve return of spontaneous circulation (ROSC) rates, it was found limiting time between compressions resulted in a better perfusion rate.[58] The AHA made the change in the guidelines to improve overall compression rate and quality based on data.

Researchers also continued to analyze data on the effect of incomplete chest wall recoil. In 2005, a study was conducted with 30 emergency services (EMS) personnel who were retrained in CPR with a focus on allowing for complete chest recoil between compressions.[59] The EMS personnel were instructed to perform CPR on a Laederal Skill Reporter manikin for three minutes. For this study, the AHA guidelines of 38 and 51 millimeters for compressions depth were used. Any compression that did not return within two millimeters of the baseline measurement was considered an incomplete decompression of the chest wall.[59] The results of the study indicated participants only achieved a complete chest wall recoil in 16.3% of compressions ($p < .0001$).[59] Incomplete chest wall compressions were observed in six out of the 13 (46%) cardiac arrest scenarios completed by EMS personnel.[59] Following completion of CPR, participants were asked to fill out a self-reported survey. The survey found participants significantly over-estimated the percentage of time they had achieved complete chest wall recoil ($p = .02$).[59] Despite the strong findings, the number of participants proved to be a limitation in this study.

In addition to the change of compression depth, the AHA released new recommendations for ventilations. In 2005, AHA guidelines suggested administration of ventilations should be completed by opening the airway by the head-tilt-chin-lift maneuver unless there is suspected trauma. The jaw-thrust maneuver is recommended to prevent injury to the cervical spine.[58] Additionally, the AHA recommended two rescue breaths be given over a time period of one second per breath, leading to a total of ten to twelve breaths per minute.[58] In the case of an advanced airway having to be inserted, the recommended administered breaths was noted to be between eight to ten per minute.[58] These changes in the guidelines over the five years allowed for improved application of ventilations while performing CPR. .

***2.2.1.6. CPR History 2010—2014***

In the 2010 AHA guideline updates, breath duration, and head positioning remained unaffected.[60] The only change made from the prior directive was the AHA specified one breath should be administered over six to eight seconds, totaling eight to ten breaths per minute.[60] The previous specifications in the 2005 guidelines stated eight to ten breaths should be administered every minute but no clarity on the duration of the breath.[58] The requirement allowed for a set time to administer a breath which can decrease the overall pause during compression application.

Although there was an emphasis to decrease time needed to administer ventilations during CPR, there is a lack of research on the topic. Researchers observed recordings of patients who experienced an OHCA and compiled 199 results.[61] Researchers analyzed data and acquired information regarding ventilation duration during CPR performance. After researchers performed a one-way ANOVA test, they found 81% of the mean compression rate were above the minimum guideline of 100 compressions/minute.[61] Additionally, the median time of compression interruptions to administer two rescue breaths was seven seconds ($25^{th}$-$75^{th}$ percentile, 6-9 seconds).[61] When these two values were combined, researchers estimated the majority of rescuers were proficient in delivering two rescue breaths under ten seconds while also keeping a consistent compression rate of 70 compressions/minute.[61]

Based on these findings, researchers concluded rescuers who performed CPR were able to deliver two ventilations while adequately administering an effective number of compressions without an adverse outcome.[61] The timing of ventilation administration is a vital factor when developing and adequate algorithm to deliver efficient and successful CPR. The findings from this study supported the implementation of mouth-to-mouth ventilations.

In addition to the changes made to ventilations, the AHA made alterations regarding the order of priorities for CPR. Historically, the order of priorities to be followed at the scene of a cardiac event was commonly known by the acronym "ABC:" airway, breathing, and circulation.[60] This meant an open airway should be established first when treating individuals in cardiac arrest, followed by ventilations, and ending with administering compressions. The AHA replaced "ABC" with "CAB:" compressions, airway, and breathing.[60] This new update allowed for immediate administration of compressions for an individual who experienced cardiac arrest.

To uphold the new evidence-based changes, researchers conducted a prospective, single-blind study. The primary purpose of this study was to determine the differences between ABCs and CAB and which had better patient outcomes.[62] A total of 108 teams were recruited. Each team consisted of one registered nurse and two general practice doctors or two internal medicine doctors.[62] Participants were instructed to perform compressions/ventilations at a ratio of 30:2 on a Human Patient Simulator manikin.[62] The teams were split into two groups. Fifty-three were assigned to perform the ABC techniques and 55 were assigned to perform the CAB technique.[62] A flow chart was given to each group providing them with instructions on how to perform the technique assigned. Each cycle of CPR began when a participant touched the patient and ended upon completion of a 30:2 compression/ventilation cycle.

Researchers ran a student's *t*-test and chi-square test when needed. A singular cycle of CPR (30:2 compression/ventilation cycle) was timed in each group and found the average time for the ABC group was 63±17 seconds and average time for the CAB group was 48±10 seconds ($p < .0001$).[62] A breakdown of time can be seen in Table 2. Based on the results of the data, researchers determined the CAB method was performed more efficiently due to the delay in start of CPR of the ABC group.

**Table 2.** Timing of Events[a]

| | ABC group (n=53) | CAB group (n=55) | p-value |
|---|---|---|---|
| **Check airway (sec)** | 8±6 | 7±8 | .79 |
| **Check pulse (sec)** | 16±13 | 8±6 | .0001 |
| **Start of rescue breaths (sec)** | 37±15 | 43±10 | .005 |
| **Start of cardiac massage (sec)** | 43±16 | 25±9 | .0001 |
| **Start of first 30:2 cycle (sec)** | 32±12 | 25±10 | .002 |
| **Length of first 30:2 cycle (sec)** | 31±13 | 23±6 | .0001 |
| **End of first 30:2 cycle (sec)** | 63±17 | 48±10 | .0001 |

[a]adapted from Marsch et al.[62]

Additionally, to deter interruption in compressions, the AHA in their 2010 recommendations minimized the importance of checking for a pulse. Based on new research, it was recommended rescuers spend no more than 10 seconds checking for a pulse.[60] This change was made due to concern over how long it took to check a pulse during resuscitation efforts.[60] Researchers conducted studies to determine if the new recommendations by the AHA were feasible for rescuers.

To determine how quickly laypersons could check a carotid pulse, researchers evaluated 449 individuals.[63] The participants were recruited from different parts of a CPR certification course. One hundred and sixty-eight were evaluated directly after a 16-hour first aid course, 202 after completion of an eight-hour CPR specific course, and 79 participants prior to attending a

CPR course.[63] Participants were asked to measure the carotid pulse of a young, healthy, and non-obese individual laying on the floor.[63] To measure the time it took participants to correctly detect the carotid pulse, a stopwatch was used.[63] On average it took participants 9.46 seconds to detect a carotid pulse.[63] Based on the average time, researchers determined only 47% of participants detected the pulse within five seconds, 74% within 10 seconds, and 2% were not able to find one at all.[63] The results of this study raised concern over a layperson's ability to detect a carotid pulse. The time spent to find a pulse can take time away from performing CPR. Although medical experts initially thought diagnosing pulselessness was critical before performing an intervention, no one thought to study the accuracy of laypeople attempting to detect a carotid pulse.

In a different study, researchers attempted to determine how confident healthcare providers were in finding a carotid pulse. A total of 64 volunteers were recruited from the French Red Cross who had extensive training with AEDs, BLS courses, and averaged three years of experience.[64] A Laederal ALS Skillmaster manikin was used to create seven different pulse rhythms.[64] The seven combinations of pulses incorporated different pulse strengths and detection time participants randomly performed.[64] Upon completion of all combinations, participants were asked based on a visual analog scale (VAS) how confident they were in being able to correctly or incorrectly detect a carotid pulse (0 = no conviction, 100 = absolute certitude).[64] The findings from the study can be found in Table 3.

**Table 3.** Results of Ability and Confidence When Assessing for Carotid Pulse[a]

| Situations | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **Time Interval (seconds)** | 10 | 10 | 30 | 10 | 10 | 10 | 30 |
| **Pulse Strength (%)** | Pulseless | Pulseless | Pulseless | Weak | Normal | Normal | Normal |
| **Performance** | | | | | | | |
| **Wrong Answer n (%)** | 27 (42) | 27 (42) | 32 (50) | 11 (17) | 5 (8) | 10 (16) | 10 (16) |
| **Right Answer n (%)** | 37 (58) | 37 (58) | 32 (50) | 53 (83) | 59 (92) | 54 (84) | 54 (84) |
| **Degree of Conviction (from 0 = no conviction, 100 = absolute certitude)** | | | | | | | |
| **Wrong Answer; Median (25-75 percentiles)** | 65 (58-100) | 72 (51-100) | 80 (50-100) | 100 (100-100) | 75 (59-100) | 90 (40-100) | 65 (33-100) |
| **Right Answer; Median (25-75 percentiles)** | 100 (52-100) | 66 (50-100) | 83 (48-100) | 100 (90-100) | 100 (100-100) | 100 (100-100) | 100 (100-100) |

[a]adapted from Lapostolle et al.[64]

Based on the results from the seven scenarios, researchers determined CPR was poorly performed in all of them.[64] The researchers noted if finding an absent carotid pulse was the only factor to initiate CPR, 50% of simulated patients would not have had CPR performed on them. Researchers thought the lack of conviction by participants could increase delays for CPR initiation.[64] A limitation to this study was the various artificial pulse strength levels on the manikin could be questioned due to its accuracy and relation to a real human pulse strength.

In an effort to mitigate the use of a simulated carotid pulse, researchers utilized 16 humans who were undergoing coronary artery bypass surgery to collect data from.[65] A total of 206 volunteers who had various medical backgrounds were selected to participate. The first group were known as EMT-1 and were laypersons who had completed an eight-hour BLS course. The second group known as EMT-2 and were EMT students who had completed four weeks of theoretical instruction and six weeks of practical instruction. The third group known as

PM-1 were paramedics who had completed one year of theoretical and practical instruction. The fourth and final group were certified paramedics known as group PM-2.[65]

Participants were instructed to find the carotid pulse on the patient's left side.[65] They were ordered to palpate for a carotid pulse for five to 10 seconds and given a maximum of 60 seconds to find the pulse. During the surgery, the patients were either in a state of nonpulsatile circulation or spontaneous circulation.[65] Assessment time began once the participant arrived at the patient's side and ended once a pulse was properly measured.[65] Out of the 206 assessments, pulses were detected in 147 assessments and in 59 assessments no pulse was found.

The substantial differences in assessments creates a convincing limitation to this study. Upon data analysis, researchers noted in 10% (6/59) of pulseless assessments, a pulse was not recognized within 60 seconds. It was also found by researchers in 45% (66/147) of pulse assessments, participants were not able to find a pulse.[65] The inconsistencies from the results can be a determining factor on whether to initiate CPR or continue monitoring the patient. The error in diagnosing has the potential to create a delay in CPR initiation, resulting in lower resuscitation rates from individuals experiencing SCA. Researchers also noted the median delay in finding a pulse was 24 seconds.[65] If a pulse was not found, the time to make a decision was longer (32 seconds; range 12-60 seconds) compared to when a pulse was present (22 seconds; range 3-55) ($p < .001$).[65] If participants were not able to find a pulse, they communicated their findings significantly later (30 seconds; range 13-60 seconds) than if they were confident they had found a pulse (15 seconds; range 3-48 seconds) ($p < .001$).[65]

The amount of training participants had completed played a role in being able to detect a pulse. The PM-1 group was able to find a pulse quicker than the EMT-1 group ($p < .02$).[65] Researchers noted only 16.5% (34/206) of participants were able to find a pulse within the 10 second recommendation by the AHA.[65] Additionally, only 15% (31/206) of participants were able correctly diagnose the patient's pulse status within the 10 second recommendation.[65] The reported findings of delayed pulse detection paired with participants' inaccurate findings raised concerns over resuscitation efforts. After all assessments were analyzed, the researchers noted high levels of inaccuracy and delay in pulse check by the participants. The ability to accurately detect a pulse during resuscitation efforts is vital to initiate CPR. Inaccuracy and low confidence levels of responders when finding a carotid pulse has negative and unnecessary delays in life saving efforts for those experiencing cardiac emergencies.

### 2.2.2. 2015/2020 AHA CPR Guidelines

The AHA has consistently revised CPR guidelines and recommendations since the inception of the committee with its focus on best practices and patient outcomes. Overall there have been changes to the overall CPR technique (Table 4).[66] Substantial changes are rare, but optimal rates are still being researched. However, the AHA continues to update guidelines about specific aspects of CPR based on contemporary research.

**Table 4.** Changes in CPR Parameter Recommendations from 1966 to 2020[ab]

| Guidelines | 1966 | 1992 | 2000 | 2005 | 2010 | 2015/2020 |
|---|---|---|---|---|---|---|
| Compression position | Lower half of the sternum | Lower half of the sternum | Lower half of the sternum | Lower half of the sternum | Center of the chest | Lower half of the sternum |
| Compression depth (cm) | 4-5 | 4-5 | 4-5 | 4-5 | ≥5 | ≥5 but ≤6 |
| Compression rate (/min) | 60 | 80-100 | ~100 | ~100 | ≥100 | 100-120 |
| Compression/ventilation ratio | 15:2 for one rescuer<br>5:1 for two rescuers | 15:2 for one rescuer<br>5:1 for two rescuers | 15:2 for one or two rescuers | 30:2 for one or two rescuers | 30:2 for one or two rescuers | 30:2 for one or two rescuers |
| Ventilation rate (breaths/min) | ~12 | 10-12 | 10-12 | 8-10 | 8-10 | 8-10 |

[a]adapted from Hwang et al.[66]
[b]adapted from AHA 2015/2020 CPR/ECC Guidelines[4]

As evident in Table 4, changes are necessary for continued best practice of CPR. Some components of CPR like ventilation rate and compression rate have gone through changes, but the ideal recommendations are still being researched.[66] Updates of guidelines are necessary as further research is conducted about CPR technique. As a result of the impending research, the AHA continues to update their guidelines based on current resuscitation research. In October of 2020, the AHA released their most recent update. Updates include reemphasizing the importance of early CPR initiation of lay rescuers and the implementation of real-time audio-visual feedback devices to maintain CPR quality.[67] The overall CPR technique from the 2020 recommendations are similar to the 2015 guideline update.

#### *2.2.2.1. Chest Compression Rate*

Currently the AHA recommends 100-120 compressions per minute.[4] This recommendation differs from the 2010 guideline update, which specified a minimum of 100 compressions per minute.[4] The change in recommendations of compression rate derives from a set of prospective studies performed by the Resuscitation Outcomes Consortium (ROC). The ROC investigated the relationship between chest compressions and patient outcomes during out-of-hospital cardiac arrests (OHCA).[4]

The first study was conducted over a two-year period where data were collected from the ROC's sites in the U.S. and Canada.[68] The ROC is a network formed to research the treatment of patients who experience OCHA throughout the U.S. and Canada.[68] Exclusion criteria for this study included those who had experienced a noncardiac or traumatic OHCA. Participants were included if they were at least 20 years old, treated by EMS in a participating ROC region, and experienced an OCHA. Additionally, electronic recordings of chest compressions for at least five minutes had to be included.[68] A total of 26,902 cases were reported but only 3,098 included analyzable CPR data.[68] The researchers conducted a logistical regression test to determine the odds ratios of the association between chest compression rate and return of spontaneous circulation (ROSC).[68] Remarkably, the researchers found when ROSC peaks at a rate of 125 chest compressions per minute or higher, the patient would decline quickly.[68] Additionally, compression depth was found to dramatically decrease with increasing compression rate ($p = .03$).[68]

There were several limitations within this study. One limitation was researchers only used data from a case if CPR data had been collected during the medical intervention. Because of this, only 20% of the reported OHCAs were able to be analyzed.[68] If the other 80% of cases were able to be used, it could have skewed the results significantly. Another limitation was researchers only analyzed the first five minutes of CPR even though some patients underwent CPR for longer than five minutes.[68] In an effort to address this limitation, researchers referenced a prior independent study that concluded chest compressions during subsequent minutes of CPR were similar to the first five minutes.[68] Despite the study's limitations, researchers provided evidence on a possible upper limit for effective chest compression rates.[68]

The second and final study influencing the AHA's change in compression rate took place from 2007-2009. This study could have been considered an attempt by the ROC to validate the results in the aforementioned study.[69] The ROC utilized the same locations across the U.S. and Canada to collect data just as they had for the previously mentioned study.[69] For this study, the ROC had almost identical inclusion and exclusion criteria. The only exception was the minimum age of inclusion which was 18 years old compared to the first study of 20 years old.[69] With this new age criterion and more ROC sites having access to proper electronic CPR monitoring equipment, the ROC was able to collect 6,399 cases, which was almost double the previous study's case number of 3,098.[68] Although researchers had nearly doubled the case load, 2,431cases could not be included because they lacked useable data.

After the data were collected, researchers organized the cases into five different compression rate categories: less than 80, 80-99, 100-119, 120-139, and ≥140.[69] The researchers analyzed data with a logistical regression to determine the association between chest compression rate and odds of patient survival to hospital discharge.[69] After adjustments for covariates like chest compression depth and chest compression fraction were made, the researchers reported compression rate of 100-119 compressions/minute were related with considerably greater odds of survival to hospital discharge than higher or lower compression rates ($p = .02$).[69] Compression rates between 100-119 compressions/minute resulted in a 10% survival rate (Table 5). Finally, researchers found compression depth decreased with increasing compression rate in a dose-dependent manner ($p < .0001$).[69] This suggests having a defined upper limit for chest compressions is beneficial when promoting proper compression depth.[69]

**Table 5.** Chest Compression Rate in Relation to Hospital Survival Discharge[a]

| Rates of compressions/minute | Survival percentages |
|---|---|
| >80/min | 9% |
| 80-100/min | 8% |
| 100-120/min | 10% |
| 120-140/min | 8% |
| >140/min | 6% |

[a]adapted from Idris et al.[69]

Although researchers were able to analyze almost double the cases in the most recent study, only 62% of all OHCA cases reported to the ROC were analyzed.[69] If the data were available, the remaining 38% of cases could have been analyzed and could have affected the results. In similar fashion to the first ROC study, this second study only analyzed the first five minutes of CPR in each OHCA even if resuscitation attempts lasted longer than five minutes.[69]

Researchers noted little difference and no statistical significance between mean compression rate after five and 10 minutes of CPR (111±16 compressions/minute vs. 113±16 compressions/minute).[69] Because of this, no conclusions were made about the statistical similarity of the two mean compression rates. A limitation in this study was the lack of data analyzed after the initial five minutes of resuscitation. Still, the study also provided insight and evidence to support having an upper limit for chest compression rates.[4]

The ROC's aforementioned studies[68, 69] were the only data used to update the AHA's new recommendations on chest compression rate.[4] However, there has yet to be an ideal chest compression rate to reduce ROSC. There is a need for more prospective cohort studies involving larger populations to research the association of chest compression rate, ROSC, and odds of OHCA survival.

#### *2.2.2.2. Chest Compression Depth*

Currently, the AHA recommends a compression depth between five and six centimeters.[4] Compared to the 2010 guidelines, the 2020 guidelines have an upper limit of six centimeters. The AHA previously recommended a compression depth of at least five centimeters.[66] The AHA's updated recommendation comes from evidence in two studies. The first was a large-scale, prospective cohort study performed by the ROC that included a relationship between compression depth and OHCA survival.[4] The second study was a small-scale, prospective observational study where researchers studied the relationship between compression depth and risk of patient injury.[4]

The large-scale cohort prospective study referenced by the AHA for their 2020 guidelines took place from 2007 to 2010 by the ROC. To validate their updated recommendation for chest compression depth, the conclusions of the study somewhat disagreed with the current CPR gudielines.[70] Similar to the ROC studies[68,69] previously mentioned, OHCA data were collected from nine ROC sites across Canada and the U.S.[70] To be included in the research, subjects had to be ≥18 years of age, experience a nontraumatic OHCA, and receive CPR from an EMS provider.[70] If a by-stander initiated CPR or if electronic CPR data was not electronically recorded, then those cases were excluded.[70] Chest compressions were measured by an accelerometer interface built into automated external defibrillators (AEDs) carried by members of the EMS team.[70] A total of 27,986 OHCA cases were reported to the ROC during the three-year period, but only 9,136 qualified for the study.[70] The first 10 minutes of resuscitation were examined by researchers and each case was followed to determine if the patient survived to hospital discharge.[70]

A multivariate logistic regression was conducted to determine the association between compression depth and patient outcome.[70] The mean compression depth from all reported cases was approximately 4.2 cm (SD=1.17 cm), which was below the AHA's recommended value of at least 5 cm of compression depth during the study period.[70] Additionally, the researchers discovered the probability of survival increased with deeper compression depths. However, once a certain depth was obtained, the chance of survival began to decrease.[70] Researchers reported a compression depth range of 4.03 cm to 5.53 cm resulted in the highest odds of survival; they noted the probability of survival peaked at a compression depth of 4.56 cm.[70]

Data were only collected from approximately 33% of all OHCA cases during the study period. In similar fashion with previous studies, the results could have been dramatically different if more of the OHCA cases used proper CPR monitoring equipment. Additionally, there was no information collected regarding potential cofounders like firmness of the surface where CPR was performed or patient body size which could have affected results.[70] The researchers concluded having an upper limit for chest compression depth is beneficial and could improve overall OHCA outcomes. It was also suggested the AHA's recommendation of at least 5 cm could have been too high.[70]

At Tampere University Hospital in Finland, researchers began to collect data on CPR quality during in-hospital resuscitation attempts to determine if there was a relationship between risk of CPR-related injury and compression depth.[71] Any adult patient who underwent resuscitation at the hospital was included in the study. Exclusion criteria included patients who had resuscitation attempts prior to arriving at the hospital or if the patient had any type of pre-resuscitation trauma in the abdominal or thoracic region.[71] Data from CPR, such as total number of compressions delivered, average compression depth, and peak compression depth were collected by AEDs that were equipped with CPR analysis features.[71]

At the end of the three-year study, injuries related to chest compressions were analyzed from forensic autopsy records, computer tomography (CT) scan, medical autopsy records, and chest x-rays of included patients.[71] Sternal or rib fractures, pneumothorax, hemothorax, laceration/contusion/bruising of the lungs or heart, damage to great veins, and damage to the spleen, liver, or stomach were all considered injuries relating to CPR.[71] A total of 370 patients were resuscitated by medical staff during the study period. Of those 370 patients, 170 were included in data analysis; 183 patients were missing post-resuscitation exam or CPR data, and the other 17 cases met the exclusion criteria.[71]

Independent samples *t*-tests were conducted to compare chest compression depth between patients who had injuries versus those who did not.[71] Throughout the course of the study, mean compression depth for injured patients was 56 mm (5.6 cm); this value was significantly different than the 52 mm (5.2 cm) mean compression depth for those who did not sustain any injuries ($p = .04$).[71] Researchers found 49% of CPR-related injuries occurred when compression depth exceeded 60 mm (6 cm).[71] When the data was divided by gender, there was a significant increase of injury rate with compression depth > 60mm with males ($p = .008$) than females.[71]

One of the limitations of this study was its sample size compared to other studies[68–70] used by the AHA. This study had a much smaller sample size of 170 patients[70] whereas other studies used by the AHA had a range sample size from 3,100 patients[68] to 9,136 patients.[70] Additionally, researchers acknowledged compression depth measured may not be entirely accurate due to limitations of the current technology.[70] At the completion of this study, the researchers concluded increased chest compression depth could lead to higher rates of CPR-caused injury, and a compression depth exceeding 60 mm could significantly increase the risk of injury in males.[70]

Comparing the AHA's 2020 compression depth recommendation to the results of the studies[70,71], the AHA's recommendations seem relatively weak. In the ROC's prospective cohort study[70], the relationship between chest compression depth and patient survival, the researchers noted the AHA's recommendation depth of ≥ 5 could be too high. Meanwhile, researchers at Tampere University Hospital found higher injury rates in patients when compression depth surpassed 6 cm with a significant association ($p = .008$) found only in male patients.[71] To be able to recommend an optimal chest compression depth, more research needs to be conducted to understand the relationship between chest compression depth, patients' survival, and risk of CPR-related injury.

#### *2.2.2.3. Hand Position During Chest Compression*

Hand position placement during chest compressions were updated in the 2020 AHA guidelines. It was recommended rescuers place their hands on the lower half of a patient's sternum instead of the previous recommendation of placing the hands on the center of the chest.[4] Hand placement during CPR lacks an abundance of research when compared to other parameters of CPR.[4,66] To uphold the 2020 recommendations on hand position placement during chest compressions, the AHA referenced two human studies. These human studies incorporated a crossover design to compare physiologic endpoints caused by different hand position placements.[4]

To validate the AHA's evidence-based recommendation, the first study cited for their new hand placement recommendation originated from research conducted in Oslo, Norway. The purpose of the study was to determine whether changing hand placement during CPR would affect the hemodynamics of a patient who experienced sudden cardiac arrest (SCA).[72] Researchers utilized ambulance services to collect data and were manned by one paramedic and one physician when dispatched for a call regarding cardiac arrest in the city of Oslo.[72] All adult patients who suffered an out-of-hospital cardiac arrest (OHCA) and were treated by the physician/paramedic crew were included in the study.[72] Hemodynamics of patients were monitored by measuring end tidal $CO_2$ ($EtCO_2$) via side-stream capnography.[72] $EtCO_2$ is known as the partial-pressure of $CO_2$ that is detected at the end of exhalation.[72] $EtCO_2$ has been well-supported in literature as a reliable indicator in its effectiveness of systemic perfusion during CPR and chest compressions on cardiac output.[73,74] The first sign of return of spontaneous circulation (ROSC) is an increase of $EtCO_2$. This concept can be utilized by rescuers to monitor the quality of delivered chest compressions.[73]

Upon dispatch of the ambulance crew, strict treatment protocols were followed for suspected cardiac arrest.[72] This began by establishing a patent airway for patients by inserting an endotracheal intubation.[72] Each physician and paramedic underwent extensive theoretical and practical training to guarantee the treatment protocol was carried out in the correct manner. Intubation tubes used were connected to an electronic capnography device capable of providing continuous $EtCO_2$ feedback.[72]

After a patient was intubated, rescuers changed hand placement several times during the first three minutes of CPR. For the first minute of CPR, chest compression rate and depth were heightened by using the $EtCO_2$ feedback as compressions were performed on the inter-nipple line (INL).[72] Over the next two minutes, $EtCO_2$ was measured in 30-second intervals at four different positions on the chest: the INL, two centimeters below the INL, two-centimeters to the right of the INL, and two centimeters to the left of the INL.[72] Upon the completion of the two-minute treatment period, chest compressions were continued in the position which had the highest $EtCO_2$ value for the remainder of CPR.[72] A total of 33 adult OHCA cases occurred during the study period; however, three were excluded.[72]

The $EtCO_2$ data were analyzed with a non-parametric Friedman's Two-Way Analysis of Variance by Ranks test to determine $EtCO_2$ value differences between hand positions.[72] There were no significant differences between the $EtCO_2$ values produced during chest compressions among the four different hand positions ($p = .04$).[72] Of the four hand placements, there were no significant differences in $EtCO_2$ values across patients.[72] The low sample size was a limitation of this study as there could have been a rise in relevant data if an increase of patients experienced OHCA. A potential cofounder for this study was compression rate and depth were not formally tracked during resuscitation attempts. Because researchers did not try to establish any relationship between hand position and patient outcomes, it limited the clinical applicability of the results. Researchers concluded the ideal hand placement during compressions can vary between patients, thereby encouraging further research into hand placement during chest compressions.

The second study the AHA incorporated for their updated 2015/2020 recommendations was a prospective clinical trial conducted at a university hospital in Korea. The primary purpose of the study was to examine the hemodynamic effects of chest compressions with two different hand positions on a patient's sternum.[74] To be included in the study, subjects had to be at least 18 years of age, suffer a non-traumatic cardiac arrest, and fail to regain spontaneous circulation in the hospital's emergency department after 30 minutes of standard CPR.[74] A total of 17 patients met the inclusion criteria.[74] For this study, standard CPR referred to a resuscitation attempt adhering to the 2010 AHA CPR recommendations and guidelines.[74]

Resuscitation attempts were initiated immediately after patients arrived at the hospital. CPR was conducted by a team of two emergency medical technicians (EMTs), two nurses, and two doctors.[74] Similar to the previous Norwegian study[72], hemodynamic effects of chest compressions were estimated by $EtCO_2$ data. The data were continuously measured by a capnography unit attached to endotracheal intubation tubes.[74] For 30 minutes of standard CPR, EMTs on the medical team completed chest compressions. The rescuers were instructed to perform compressions at a rate of 100 compressions per minute and to position their hands on the patient's INL in the center of the chest.[74] A metronome was used to help rescuers keep consistent compression rates. If after 30 minutes of standard CPR a patient did not experience ROSC, the rescuers switched hand placement to an alternate, more caudal position on the infrasternal notch. They continued compressions for an additional two minutes.[74]

A paired *t*-test was conducted to determine any significant differences in $EtCO_2$ values between the two hand positions.[74] The mean $EtCO_2$ values produced by the alternate hand position were significantly higher than values produced by standard hand placement ($11.0 \pm 6.7$ mmHg vs. $9.6 \pm 6.9$ mmHg, $p = .02$).[74] This suggests positioning of one's hands lower on the sternum may result in more effective chest compressions.[74] Despite the results, there were additional limitations in addition to the small sample size. Even though a metronome was used to assist with consistent compressions, there were no tools utilized to measure compression depth.[74]

Additionally, resuscitation was not started until after a patient arrived at the hospital's emergency department. The alternate hand position was not used until after 30 minutes of CPR, which could have affected the hemodynamics of the patient. The researchers also did not examine whether the alternate hand position resulted in an increased rate of injury during CPR.[74] Having one's hand over the distal end of the sternum has the possibility to result in an increased risk of a fracture of the xiphoid process. The fracture would be an unwanted effect of the new hand position. It was concluded the distal hand placement could be more effective than the AHA's recommendation of hand placement at the INL, but the limitations previously discussed in this study make it difficult to rely on these results for clinical practice.

After the AHA cited the previously mentioned studies[72,74] to validate their updated hand placement, the AHA admitted the research studies do not provide consistent or conclusive evidence regarding the effect of hand placement on resuscitation efficacy.[4] Based on the two studies mentioned, it is clear further research on hand placement during compressions needs to be completed. The optimal hand position during CPR remains unknown until further research can be completed.

#### ***2.2.2.4. Chest Wall Recoil***

The biggest difference between the 2010 AHA recommendations and the 2015/2020 AHA recommendations for chest wall recoil is the addition of instructing rescuers to avoid leaning on a patient's chest between compressions.[4] For CPR to be effective, a full chest wall recoil is imperative. When the chest is able to fully recoil, it creates negative intrathoracic pressure that promotes cardiopulmonary blood flow and venous return.[4] For the AHA's 2015/2020 recommendations, two animal studies were used as evidence to avoid leaning in between compressions. There is currently no research available on the association between chest wall recoil, leaning, and patient outcomes.[4]

The first study referenced by the AHA was conducted by researchers at the University of Arizona.[75] Ten piglets were anesthetized via an electrode placed in the animals' right ventricle followed by induced ventricular fibrillation (confirmed by attached ECG).[75] Next, CPR was provided by a rescuer while a device was secured to the animal's chest. The device simulated three different levels of residual lean during the recoil phase of chest compression: no force; 10% of the average force required to maintain 80-90 mm Hg peak aortic systolic pressure (1.8 kg); and, 20% of the average force required to maintain 80-90 mm HG peak aortic systolic pressure (3.6 kg).[75] Each trial consisted of six, three-minute CPR sessions.[75] The first and last sessions were performed without any simulated lean, and the remaining four were randomly assigned 10% or 20% simulated lean.[75] A neuron-activated microsphere assay technique monitored left ventricular myocardial blood flow (MBF) to determine the effect of residual leaning on cardiopulmonary blood flow.[75]

MBF data was analyzed by a Mann-Whitney U test to determine statistically significant differences between the three simulated levels of residual leaning.[75] The researchers found MBF decreased considerably during CPR sessions with simulated leaning compared to sessions without any leaning ($p < .05$).[75] Interestingly, they did not find any significant difference in MBF between 10% and 20% of a residual lean ($p < .05$).[75] This suggests decreased hemodynamic effects of the simulated leaning were primarily due to lack of a full chest recoil.[75] The data insinuates even a slight lean can inhibit full chest recoil. CPR hemodynamics were improved once residual leaning was removed after 16 minutes of performing CPR.[75] These observations highlight the importance of developing corrective and directive feedback CPR devices that reduce leaning while performing CPR.[75]

The second study supported by the AHA's 2015/2020 recommendation against leaning was performed to determine the effects of residual leaning on hemodynamics during CPR.[76] Ventricular fibrillation was introduced to nine piglets by researchers via an electrode placed in the animals' right ventricles. Following ventricular fibrillation, five minutes of CPR were carried out by a mechanical piston.[76] The piston was set to compress the piglets' chests to a depth equal to 25% of its anteroposterior diameters at a rate of 100 compressions per minute.[76] For the first three minutes of CPR, the piston was programmed to allow full chest recoil between compressions.[76] In the fourth minute of CPR, the piston was set to recoil only 75% of the way in order to simulate the effects of residual leaning.[76] In the fifth and final minute of CPR, full chest recoil was resumed.[76]

The data were analyzed with a one-way, repeated measures ANOVA to determine the effects of a simulated lean on subject hemodynamics.[76] As depicted in Table 6, the researchers found significant decreases in systolic blood pressure, diastolic blood pressure, mean arterial pressure, and coronary perfusion pressure during CPR with simulated leaning ($p < .05$).[76] The previously mentioned hemodynamic values remained low even when full chest recoil was resumed.[76] These results indicated even short periods of inadequate chest wall recoil can have a negative effect on a patient's hemodynamics during a resuscitation attempt.

A limitation of this study was researchers did not measure actual cerebral or coronary blood flow leading to an under/over-estimate of vital organ perfusion.[76] For this study, since the lean was simulated by decreasing the pistons' compression distance to 75% of its original depth, it is possible the noted hemodynamic decreases could be due to the 25% decrease in stroke length rather than a true residual lean.[75,76] Regardless, the researchers concluded incomplete chest wall recoil due to simulated leaning negatively effects subject hemodynamics during CPR.[76]

**Table 6.** Hemodynamic Parameters at Baseline, 100% Chest Recoil, and 75% Chest Recoil[a]

| Hemodynamic Measure | Baseline (Pre-Arrest) | 100% Chest Recoil | 75% Chest Recoil (Simulated lean) |
|---|---|---|---|
| Systolic Blood Pressure | 94 ± 6 mmHg | 74.6 ± 4.3 mmHg | 65.3 ± 5 mmHg |
| Diastolic Blood Pressure | 63 ± 4 mmHg | 28.1 ± 2.5 mmHg | 20.7 ± 1.9 mmHg |
| Mean Arterial Pressure | 73 ± 3 mmHg | 52 ± 3 mmHg | 43.3 ± 6 mmHg |
| Coronary Perfusion Pressure | 61 ± 3.2 mmHg | 23.3 ± 1.9 mmHg | 15.1 ± 1.6 mmHg |

[a]adapted from Yannopoulos et al.[76]

The two animal studies[75,76] cited by the AHA for their 2015/2020 recommendation for chest recoil guidelines are not adequate to support their recommendation. Animal studies are often difficult to generalize and apply to their human counterparts. Additionally, one of the aforementioned studies[76] may not have effectively simulated a residual lean. To fully understand the hemodynamic effects of leaning during CPR, further research involving human subjects needs to be conducted before future recommendations on chest recoil and leaning can be published.

### 2.2.3. CPR Quality

#### *2.2.3.1. Definition and Clinical Impact*

The definition of high-quality CPR has evolved over the past 50 years. As the definition advanced, the technique of CPR also evolved. In current clinical practice, providing high-quality

CPR requires following all of the American Heart Association's (AHA) current guidelines in metrics such as chest compression rate, depth, fraction, and chest recoil.[4] While independent relationships between out-of-hospital cardiac arrest (OHCA) survival and compression rate[68,69] and depth[70] are supported by contemporary literature, there is marginal evidence. The evidence regarding the collective influence of the AHA's proposed recommendations of high-quality CPR on OHCA survival is minimal.[77]

One of the only studies conducted examining the association between compliance with AHA CPR guidelines and OHCA survival rates was explored by researchers. This study was a secondary analysis of CPR data prospectively collected over a four-year period by the Resuscitation Outcomes Consortium (ROC).[77] Electronic data was collected from AEDs available during all OHCA calls at 10 ROC sites (across U.S. and Canada). The CPR data included chest compression fraction, compression depth, and compression rate. Researchers defined high-quality CPR in accordance with the 2015 AHA CPR gudielines.[77] However, the researchers decided to use a chest compression fraction of >80% compared to the AHA's minimum recommendation of >60%.[77] Cases where patients did not receive at least three minutes of AED-measured electronic CPR data were excluded, while patients who experienced a non-traumatic OHCA were included.[77] All patients had to be older than 18 years of age.[77] A total of 55,568 OHCAs were treated by EMS providers, but only 19,568 cases met the inclusion criteria.

Data were analyzed by multiple regressions adjusted for potential cofounders such as age, sex, initial cardiac rhythm, and time from dispatch to EMS arrival to examine the association between high-quality CPR and OHCA survival.[77] In conjunction with the study's definition, high-quality CPR was provided in only 1.7% of all OHCA cases.[77] Overall, unadjusted survival rates did not significantly differ between AHA guideline-compliant and non-guideline-compliant groups (7.6% vs 7.7%, respectively).[77] When restricting cases to those with late return of spontaneous circulation (≥10 minutes of CPR), the researchers found a significant association between guideline compliance and increased survival (OR=2.17, 95% CI 1.11-4.27).[77]

Researchers provided several explanations for their results. For example, those in the guideline-compliant group may have been more likely to have a poor prognosis. Even though both groups were similar in demographic characteristics, individuals who received high-quality CPR were less likely to present with a shockable (treatable) rhythm such as ventricular tachycardia or ventricular fibrillation than individuals who did not receive high-quality CPR.[77] Individuals with an initial shockable rhythm may have experienced early defibrillation, which is associated with higher OHCA survival rates.[77] Another limitation of the study was the significant differences in initial rhythm between both groups, which could have skewed the study's results. An explanation given by researchers is high-quality CPR may only be effective in a select group of individuals who experience a late ROSC.[77]

Although the researchers acknowledged the clinical importance of their explanation, their conclusions are limited because spontaneous circulation (ROSC) cannot be predicted. Ultimately, it was concluded complying with AHA CPR guidelines was not associated with improved OHCA outcomes. Based on the findings, further development of strategies that improve guideline compliance should be investiaged.[77]

#### *2.2.3.2. Factors affecting CPR Quality*

Delivering high-quality CPR is essential for increasing an individual's odds of cardiac arrest survival.[4] An important feature of CPR research is determining factors affecting a rescuer's ability to effectively perform the medical intervention. If associations are established between CPR quality and certain aspects, rescuers can modify those factors to increase the effectiveness of their CPR implementation. Over the years, researchers have identified multiple factors such a physical and cognitive aspects that can impact CPR performance.[10,78]

#### *2.2.3.2.1. Demographic Characteristics*

Certain demographic characteristics such as an individual's weight, body mass index (BMI), and sex can play a role in CPR performance.[78–80] BMI is a value used to estimate an individual's body density. It is calculated by dividing an individual's mass (in kilograms) by height (in meters) squared. After an individual's BMI is calculated, the score is used to determine if the individual is underweight (BMI < 18.5 $kg/m^2$), normal weight ( BMI 18.5 to 25 $kg/m^2$), overweight (BMI 25 to 30 $kg/m^2$), or obese (BMI > 30$kg/m^2$).[81]

In a cross-sectional study conducted by Jaafar et al.[79], researchers examined the association between rescuer gender, BMI, and quality of chest compressions. Inclusion criteria required participants to be healthcare providers who were at least 18 years of age and were healthy (no chronic diseases of physical disabilities).[79] Additionally, the participants could not have received CPR training within the past two years. These strict inclusion criteria were set in order to standardize the particiapnts.[79] A total of 74 participants were recruited for the study to receive CPR training from the same instructor in accordance with the 2010 AHA guidelines They returned to the testing site one week later to complete a CPR assessment.[79]

The assessment was made up of five cycles of CPR (30 chest compressions followed by two ventilations) administered to a Resusci Anne SkillReporter manikin. Average chest compression rate was calculated by dividing the total number of chest compressions delivered during the assessment (150 compressions) by the total time taken to completion.[79] For the five cycles of CPR to qualify as effective, a score of >80% of all compressions had to be the correct depth and an average compression rate of ≥100/min.[79] On the same day as the CPR assessment, each participant's height and weight were measured in meters and kilograms to calculate his/her BMI.[79] After participants' BMIs had been calculated, they were put into two groups: BMI <26 or BMI > 26.[79]

At the end of all the assessments, data were analyzed via a nonparametric Chi-square test for independence to examine the relationships between gender, BMI, and CPR quality.[79] A significantly higher proportion of participants in the <26 BMI group achieved >80% chest compressions with adequate depth (82% of subjects vs. 72% of subjects, $p = .04$) as well as an adequate compression rate (91% of subjects vs 50% of subjects, $p = .00$).[79] Although the most significant difference between gender in regards to CPR performance was chest compression rate, all of the female subjects maintained an adequate compression rate. In contrast, only 40% of male subjects met the criteria for an effective compression rate ($p = .00$).[79] No significant associations were found between gender and compression depth, even though a higher percentage of female subjects reached an effective depth compared to male subjects (76% vs 67%, $p = .05$).[79]

There were several limitations present for this study. Frist, all subjects received CPR training a week prior to the assessment and had an instructor in the room during the testing period coaching them on the correct hand placement.[79] In a true OHCA, the likelihood is high rescuers will not have an individual coaching them through the resuscitation process. Furthermore, there is a low probability rescuers will have undergone recent CPR renewal. With recent training and coaching taking place during the assessment, this could have led to skewed results. Additionally, it is possible resuscitation efforts will take longer than five cycles of CPR.

Having a longer assessment and excluding live coaching during the assessment could have yielded more accurate results.

The findings from the previously mentioned study[79] conflict with a study by Sayee et al.[80] The study examined factors influencing CPR performance of entry-level doctors.[80] At a teaching hospital in Belfast, all first-year doctors were invited to join the study and allowed to participate if they had received formal CPR training within three months of the study period.[80] The average BMI of the 34 participants was 24 $kg/m^2$ , and the subjects were categorized as above average (BMI > 24 $kg/m^2$) or below average (BMI < 24$kg/m^2$).[80] As part of the study, participants were required to perform two, three-minute bouts of CPR on the same type of Resusci Anne SkillReporter manikin used by Jaafar et al.[79] study. Data on chest compression depth were collected in a similar manner.[80] In one of the sessions, participants had a compression-to-ventilation ratio of 15:2. For the other session, participants had a compression-to-ventilation ratio of 30:2.[80] For this study, CPR was defined as being effective if >80% of the compressions reached an adequate depth.[80]

The CPR data were analyzed by a Mann-Whitney *U* test, and the researchers found significant differences in chest compression depth between genders and BMI groups.[80] A significantly higher proportion of male doctors compared to female doctors administered effective chest compressions (83.3% of males vs 25% of females, $p = .005$). Doctors with above average BMI performed more effectively than those with a lower BMI (76% of subjects with BMI >24 vs 35% of subjects with BMI <24, $p = .045$).[80] The study's findings regarding the relationship between BMI and chest compression depth is contrary to the results of Jaafar et al.[79], who found a significant association between low BMI levels and increased chest compression depth. The latter attribute the discrepancy in results to differences in mean BMI in each study. In the Jaafar et al.[79] study, the researchers had a mean BMI of 26 $kg/m^2$, which is categorized as overweight. The researchers[79] claimed overweight individuals have a predisposition of having a faintly abnormal position during CPR, which could affect compression depth.[79] Another contrast in the Sayee et al.[80] study was their significant association between gender and chest compression depth. The study found males were more likely to administer chest compressions at an adequate depth, whereas the previously mentioned study[79] found no significant difference between genders. Sayee et al.[80] noted the sample size (n = 34) could have played a role in their statistical findings; which could explain the differences in results from Jaafar et al.[79]

Although there were differing results, there seems to be some association between CPR quality and an individual's demographic qualities. However, further research consisting of larger sample sizes and more realistic assessments need to be completed to establish the association's true nature. With further research being conducted, researchers can begin to establish the best way to teach and certify individuals depending on their demographic qualities.

***2.2.3.2.2. Rescuer Fitness, Strength, and Fatigue***

CPR can be physically demanding for rescuers to perform. It can especially be taxing if resuscitation efforts are prolonged. As a result, how long an individual can perform high-quality CPR could be impacted by aspects of rescuers' physical fitness.

A study by Ock et al.[8] examined the influence of a CPR provider's physical fitness on the quality of chest compressions delivered during the first five minutes of resuscitation. A total of 47 participants who were medical students with basic life support (BLS) training at the Catholic University of Korea volunteered to participate in this study.[8] Each participant underwent multiple physical fitness assessments to measure maximal aerobic exercise capacity ($VO_2$max), upper body muscular strength, and upper body endurance (both via hand-grip dynamometer).[8]

After each participant had completed the required physical exams, they performed five minutes of CPR on a Resusci Anne manikin. For this study, the researchers defined quality chest compressions as those reaching a depth of five centimeters.[8]

Participants were monitored for rating of perceived exertion (RPE), heart rate, and volume of oxygen consumption per minute ($VO_2$) during the assessment.[8] RPE was determined on a 15-point scale via interview at the passing of one, two, three, four, and five-minute mark of CPR. Heart rate and $VO_2$ were continuously recorded via heart rate monitor and gas analyzer.[8] The collected data were analyzed by a one-way repeated measures analysis of variances to compare CPR quality during each minute of resuscitation. It was then analyzed by multiple linear regressions to examine the possible relationship between CPR quality and measures of physical fitness.[8]

While a consistent rate of chest compressions at 110 compressions/minute was maintained across all subjects during the five minutes of CPR, researchers found a significant reduction in quality chest compressions after each consecutive minute ($p < .001$).[8] Across all participants, the average percentage of quality chest compressions was 78.8% in the first minute and 57.2% in the second. Followed by 43.4% in the third, 36.5% in the fourth, and finally 28% in the fifth minute.[8] Participant fatigue was deemed by researchers as the main reason CPR quality decreased. Average heart rate, $VO_2$, and RPE across all participants increased significantly during CPR ($p < .001$). Additionally, there was a positive correlation between upper body muscle strength and CPR quality ($r = .494$, $p < .05$). [8] Researchers concluded fitness programs incorporating strength training may be more beneficial to CPR providers than a program focusing on cardiorespiratory fitness alone.[8]

A limitation in this study was participants' $VO_2$max were estimated via submaximal cycle ergometer test.[8] If there had been a more accurate $VO_2$max test utilized, it is possible a correlation between aerobic capacity and CPR quality could have been observed. Another limitation of this study was the short CPR performance time; this is similar to previously discussed studies[79,80] regarding the factors influencing CPR quality. It is possible a true OHCA resuscitation attempt would last more than five minutes. This highlights the importance of rescuer strength and fitness to prevent fatigue and a decrease in CPR quality. Finally, participants were asked to rate their perceived exertion at the end of each minute of CPR. This could have impeded their concentration and led to a reduction in chest compression quality. Even with the limitations discussed, the results of the study provide a compelling argument to support the proposed association between rescuer fitness and CPR quality.[8]

A randomized, crossover trial was conducted by researchers to examine the objective parameters of physical fitness that affect chest compression quality.[9] Inclusion criteria for participants were they had to be healthy (no chronic illness or physical disabilities) and certified in both basic and advanced life support (ALS). This resulted in a sample size of 40 volunteers.[9] Because of the relatively strict inclusion criteria of ALS certification, the study population consisted of paramedics, physicians, and intensive care nurses.[9]

Two days prior to CPR testing, physical fitness of each participant was evaluated by two ergometric endurance tests.[9] The first physical fitness assessment, designed to focus on upper body fitness, consisted of a three-minute ramp protocol on a rowing ergometer.[9] Participants begin at 25 watts and gradually increased resistance to a minimum of 75 watts by the end of the protocol. To have the intensity increased, participants had to maintain a stroke frequency between 30 and 40 strokes per minute.[9] However, researchers used subject heart rate at 75 watts

($HR_{75}$) as the objective marker of upper body fitness. It had the highest correlation with ergospirometric parameters during rowing ($r = -0.85$, $p < .05$).[9]

The second assessment focused on lower body fitness. This required subjects to pedal on a cycle ergometer with increasing intensity until a heart rate of 170 was reached.[9] Personal watt capacity at a heart rate of 170 was previously validated as a parameter for lower body fitness.[9] A chest-belt heart rate monitor was used to measure heart rate during each test. Subjects were given two hours to recover between fitness assessments.[9]

Two days after the fitness assessments, subjects performed two, nine-minute sequences of CPR. One sequence incorporated a compression/ventilation ratio (CVR) of 30:2 and another encompassing a CVR of 15:2.[9] The time of nine minutes for duration of CPR was chosen because, at the time of the study, it was reported as the average length of resuscitation given by bystanders in an OHCA prior to EMS arrival.[82] The CVR for the first sequence was randomly assigned to each subject via computer-generated list.[9] After the first CPR sequence, participants were given 90 minutes to recover before performing another bout of CPR using the remaining CVR.[9] Similar to previous CPR studies,[8,79,80] a Resusci Anne manikin was used for chest compressions. Quality chest compressions were defined by the AHA's 2010 guidelines. To be deemed effective, chest compressions had to be performed at a rate of approximately 100 per minute at a depth of four to five centimeters.[9] There was no corrective feedback given to subjects during the duration of testing.[9]

A two-way ANOVA statistical analysis was conducted to determine strength of association between fitness parameter and chest compression characteristics.[9] Significant correlations ($p < .001$) between personal watt capacity ($PWC_{170}$) , $HR_{75}$, and mean compression depth during both 15:2 ($r = 0.42$ and $-0.57$, respectively) and 30:2 ($r = 0.40$ and $-0.57$, respectively) CVR protocols.[9] Increasing levels of lower and upper body fitness corresponded to higher levels of $PWC_{170}$ and lower values of $HR_{75}$. Based on these correlations, researchers suggested an increase in rescuer fitness could lead to more effective chest compressions. Furthermore, $HR_{75}$ was significantly correlated ($p < .001$) with both the fraction of chest compressions with a correct compression depth ($r = -0.55$ and $r = -0.38$ for CVRs of 15:2 and 30:2, respectively) and the fraction of chest compressions with an inadequate depth ($r = 0.6$ and $r = 0.53$ for CVRs of 15:2 and 30:2, respectively).[9] Because of this data, researchers designated upper body fitness as the best predictor of chest compression quality in the study.[9]

These findings support the results of the aforementioned researchers[8] who determined upper body strength to be an accurate predictor of CPR quality. Additionally, Russo et al.[9] reported a significant decrease ($p < .05$) in compression depth within the first four minutes of CPR across all participants, which aligns with the findings in Ock et al.[8] concerning the effects of rescuer fatigue on CPR quality. Although the study was well designed, there were several limitations. Because of the strict inclusion criteria, the population of the study consisted of healthcare providers who were trained in ALS. Thus, the results of the study may not be applicable to laypersons who are present at an OHCA or other first responders who are only trained in BLS. Furthermore, rescue breaths were only imitated during the CPR assessments. Providing actual rescuer breaths during CPR could have an effect on rescuer fatigue, which could have led to different results in the study.[9] Russo et al.[9] concluded physical fitness is positively correlated with sustained, high-quality CPR but recommended the use of upper body fitness tests to more accurately predict a rescuer's quality of CPR.

With the results of the previously mentioned studies,[8,9] there is growing evidence supporting an association between rescuer physical fitness, fatigue, and CPR quality. The results of Ock et al.[8] and Russo et al.[9] suggest upper body strength is the most important tool to determine rescuer fatigue and maintain quality chest compressions through a resuscitation attempt. Although these studies provide a strong foundation, there should be further research that consists of large and diverse sample sizes, more realistic CPR assessments, and prospective data collection. The prospective data collection is required to determine the true association between physical fitness and CPR quality. There is enough current evidence to support the promotion of exercise and strength training for CPR providers.

#### *2.2.3.2.3. Self-Efficacy*

Perceived self-efficacy, or confidence, could play a role in a rescuer's ability to perform high-quality CPR. Self-efficacy is one's confidence to effectively perform a certain skill or behavior regardless of the situation.[10] The first theoretical construct of self-efficacy was developed in 1977 by Albert Bandura, a social psychologist.[83] Bandura's theory states "initiation of a given behavior is likely to occur depending on one's perceived self-efficacy expectation, outcome expectation, and outcome value".[84] Self-efficacy expectation is the belief one can effectively perform a certain skill and the desired outcome is expected.[83] Self-efficacy has been previously shown to affect the likelihood of laypersons to initiate CPR,[19,85,86] but research examining the association between self-efficacy and CPR quality is limited to investigations of various healthcare providers.[10–12]

Researchers conducted a study to examine the association between CPR skills with self-efficacy and overall CPR knowledge in nursing students. A total of 124 nursing students were recruited during their clinical rotation at a hospital in Seoul.[10] The researchers did not specify any inclusion or exclusion criteria to participate in the study.[10] Participants attended a 30-minute lecture covering current CPR guidelines. Upon completion of the lecture, participants attended an hour-long, hands-on CPR training session.[10] Directly after the training session, participants completed a two-item perceived self-efficacy assessment.[10] The items on the assessment were taken from the Resuscitation Self-Efficacy scale for nurses, which is a 17-item scale created previously and tested for validity by Roh et al.[87] The two items required participants to use a five-point, Likert-type scale to rate their confidence in performing adequate chest compressions and artificial ventilations via bag valve mask.[10] Higher scores were indicative of higher levels of self-efficacy.[10]

Additionally, subjects were given a 10-item, multiple choice questionnaire to assess CPR knowledge. The questionnaire consisted of six questions on the principles of basic life support (BLS) followed by four questions about chest compressions and ventilations.[10] Upon completion of the self-efficacy survey, participants performed CPR on a Resusci Anne manikin.[10] Researchers were able to use the data to evaluate the participants using a numerical penalty scoring system.[10] No points were given to participants if they were able to perform a skill correctly by adhering to the 2010 AHA recommendations.[10] If a student performed a skill incorrectly, a value of 10 or 20 penalty points were given for the skill.[10] Thus, a lower penalty score indicated a higher quality of CPR.

Data were analyzed via multiple linear regression to examine the association between perceived self-efficacy and CPR performance.[10] The researchers found a statistically significant negative correlation between compression skills' penalty score and self-efficacy ($r = -0.238$, $p = .008$) suggesting students who reported higher perceived self-efficacy for chest compressions were more likely to perform them correctly.[10] Although ventilation skill was not significantly correlated with ventilation self-efficacy ($r = -0.031$, $p = .730$), neither compression nor ventilation skills were correlated with knowledge of compressions ($r = -0.060$, $p = .510$) or knowledge of ventilations ($r = -0.103$, $p = .257$).[10] Finally, researchers found a significant positive correlation between total self-efficacy and total CPR performance ($r = 0.313$, $p < .001$). This indicated subjects with higher confidence levels were also knowledgeable about CPR.[10] These findings suggest rescuer confidence is possibly gained through psychomotor practice and could be a better predictor of CPR skill performance rather than written exams. Based on the results of this data, even though a rescuer is knowledgeable about CPR, there is a possibility they may not perform high-quality CPR.

A limitation in this study pertains to the methods used to measure student knowledge and self-efficacy. Although both assessments were adapted from previously validated tools,[10,87] they each contained small number of items. There is a possibility having a limited number of survey items was not sufficient to accurately measure subject's knowledge and self-efficacy, possibly leading to skewed results. Additionally, duration of CPR skills test or any demographic characteristics besides gender and age were not reported by the reseachers.[10] Cofounding variables like rescuer BMI and fatigue were not considered or controlled in the study.

Researchers concluded if the correlation between self-efficacy and chest compression is valid, then BLS courses should incorporate more hands-on mastery experiences to maximize student self-efficacy.[10] Integrating additional psychomotor practice during CPR training is imperative to allow participants to feel like they have mastered CPR skills. If participants feel as if their skill has been mastered, they could feel more confident and more likely to initiate bystander CPR.

A similar study by Gonzi et al.[12] examined the correlation between CPR quality and self-efficacy in hospital staff using in-hospital cardiac arrest simulations. A total of 320 participants consisting of mostly nurses (approximately 45% of subjects) and doctors (approximately 43% of subjects) were recruited from current staff at a hospital in Italy.[12] To be included, the participants were required to have attended a five-hour BLS certification class consisting of instructional videos, lectures, and CPR skill practice within 12 months of the study being conducted.[12] To correctly measure CPR quality, subjects were paired and asked to complete a five-minute cardiac simulation using a Resuci Anne manikin. The manikin was placed in a hospital bed and used as the simulated cardiac arrest patient.[12] During the assessment, CPR compression rate and depth were measured electronically via the manikin.[12] Before and after testing, each participant was asked to rate their perceived self-efficacy to effectively perform resuscitation on a 10-item, Likert-type scale questionnaire.[12] Higher scores were indicative of higher confidence levels.[12]

After testing was completed, a bivariate analysis was conducted to determine the presence of any correlation between CPR quality and self-efficacy.[12] Upon data analysis, the researchers found no significant correlation between pre-test self-efficacy and CPR performance for overall chest compression quality ($r = 0.059$), chest compression rate ($r = -0.032$), or chest compression fraction ($r = 0.123$).[12] These findings could be attributed to participants over estimating their CPR skills. Equally, all three measures of CPR quality were significantly correlated with post-test self-efficacy ratings as seen in Table 7. Subjects seemed to provide a more accurate estimation of CPR skills and the confidence associated with performing them upon completion of their simulation. These findings are similar to the aforementioned study[10] that suggest self-efficacy could play a role in CPR performance.

A strength of this study compared to other examinations of CPR quality[9,10,80] is the effort made to simulate a realistic cardiac arrest. The participants had to perform CPR skills on a manikin positioned in a hospital bed and had to work together to retrieve emergency supplies such as an AED.[12] Additionally, researchers only used one item to assess self-efficacy.[12]

Incorporating a more-developed tool consisting of multiple items assessing self-efficacy for a variety of CPR skills rather than overall CPR performance could have resulted in more accurate results. The researchers concluded by suggesting perceived self-efficacy does not necessarily affect CPR performance.[12] However, the significant correlations found between CPR quality and post-test self-efficacy ratings suggest individuals who undergo simulated CPR training may be able to use self-efficacy to predict CPR performance.

**Table 7.** Correlation Between CPR Metrics and Self-efficacy Before and After CPR Simulation[a]

| CPR Metric | Pre-Test | Post-Test |
|---|---|---|
| Chest compression fraction | r = 0.123, *P* > 0.05 | r = 0.240, *P* < 0.01 |
| Compression quality | r = 0.059, *P* > 0.05 | r = 0.166, *P* < 0.05 |
| Correct compression rate | r = -0.032, *P* > 0.05 | r = 0.212, *P* < 0.01 |

[a]adapted from Gonzi et al.[12]

In an attempt to examine healthcare workers' abilities outside the traditional hospital setting, researchers studied certified athletic trainers (ATCs) and investigated their relationship between CPR quality and self-efficacy.[88] Researchers recruited 50 athletic trainers to participate from across the Midwest region through word-of-mouth and email. The ATCs years of experience ranged from one to 34 years. Inclusion criteria consisted of being a certified athletic trainer through the Board of Certification (BOC®) and currently certified in CPR/basic life support (BLS).[88] Participants were excluded if they had a current or systemic musculoskeletal condition that inhibited them from performing high-quality CPR.

Upon arrival, participants completed a 14-item CPR self-efficacy questionnaire modified from the Basic Resuscitation Skills Self-Efficacy Scale by Hernandez-Padilla et al.[89] The first five items prompted participants to consider how confident they were in carrying out the five practice domains of athletic training.[88] The remaining nine statements examined their confidence in performing specific aspects of CPR in accordance with the 2015 AHA guidelines. Participants rated their level of confidence using a six-point, Likert-type scale ranging from "Strongly Disagree" to "Strongly Agree".[88] In addition to the questionnaire, participants were also required to perform a one-minute CPR proficiency test. To be considered proficient, participants had to attain an overall QCPR score of 80% or higher. If the participant did not meet the 80% score, the researcher provided feedback and allowed the participant to practice and take the proficiency test once more.[88]

Upon the completion of the one-minute proficiency test, participants took up to a five-minute break. At the conclusion of the break, participants performed eight minutes and 59 seconds of single-rescuer CPR. The time for administering CPR was chosen because it is the national standard for EMS response time.[88] No audio or visual feedback was given since research suggests these factors may impact overall CPR performance.[12,88,90] The researchers recorded: overall QCPR score, compression score, ventilation score, chest compression fraction, hand placement, mean compression depth, full recoil percentage, full depth percentage, proper compression rate percentage, mean rate, percent of ventilations that were adequate, percent of ventilations that were inadequate, and total time testing.[88] Directly after the testing, participants were asked to respond to the 14-item CPR self-efficacy questionnaire for a second and final time.

The researchers conducted a Pearson product-moment of correlations to analyze the relationship between self-efficacy and CPR ability. This test was computed between self-efficacy and 11 dependent variables consisting of CPR parameters and participant's demographics to identify any associations.[88] In addition to the Pearson product test, linear regressions were also performed to determine if any and to what degree self-efficacy plays a role in overall CPR performance and to what degree years certified, gender, and educational background relate to CPR self-efficacy.[88] A paired samples *t*-test was conducted to compare CPR self-efficacy values from before and after CPR assessment. Finally, basic descriptive statistics were used to determine the percentage of ATCs who achieved satisfactory performance in compression rate, depth, chest compression fraction, and ventilation depth.

Researchers found there was a small prevalence of a negative correlation between self-efficacy and CPR metrics. Across all participants, CPR confidence was high. The high confidence did not change significantly after performing CPR ($p = .792$). Out of the 11 CPR dependent variables, hand position had the most statistically significant negative correlation with self-efficacy ($r = -.26$, $p = .07$).[88] Interestingly, even though ATCs were confident in their ability to administer CPR, only 20% delivered adequate ventilations and 54% did not maintain a proper chest compression rate of 100-120 compressions per minute.[88]

While this was the first study to examine CPR self-efficacy within ATCs, these results do not support the previously mentioned studies[10,12] suggesting a positive relationship between several CPR measures and self-efficacy. The study indicated ATCs might be over confident about their CPR performance. Once ATCs are certified by the BOC®, they are required to maintain a current CPR certification. Between renewal of CPR certification, there is no requirement for ATCs to practice their psychomotor skills. Implementing booster sessions could improve ATCs' self-efficacy when performing high-quality CPR.

It is difficult to make definitive conclusions about self-efficacy's effect on CPR quality from the results of the contemporary literature due to study limitations and lack of research.[10,12] There is a need for further research focusing specifically on the relationship between rescuer confidence and CPR performance that utilizes larger sample sizes, more realistic scenarios, and detailed self-efficacy assessments. As future research is conducted, researchers should expand sample populations to include laypersons as well as a wider range of healthcare providers. Even so, these studies still seem to support an association between hands-on simulation training, self-efficacy, and CPR performance.[10,12]

#### *2.2.3.3. Deliberate Feedback*

Throughout the years, different cardiopulmonary resuscitation (CPR) feedback devices have been developed and implemented into education sessions. Research shows instructor assessment of chest compression quality is not accurate. As a result, feedback devices are implemented to decrease subjective nature of instructor instructions.[13] The lack of accurate feedback from instructors presents challenges in determining whether individuals can correctly perform high-quality CPR. To combat these new challenges, the American Heart Association (AHA) introduced guidelines requiring the use of feedback devices in all adult CPR training courses.[91] Using feedback devices during CPR training for healthcare providers has indicated an increase in overall CPR performance; however, there is minimal research regarding laypersons/bystanders.[13,90] Bystander-initiated CPR is an important step in the AHA's chain of survival and decreasing out-of-hospital cardiac arrest (OHCA) associated deaths.[4] Using feedback devices during CPR trainings can provide a strong foundation for CPR psychomotor skill acquisition and retention.[13,90,91]

To demonstrate the effectiveness of feedback devices in laypersons, researchers aimed to determine if using CPR feedback improved overall CPR quality.[13] A secondary purpose of this study was to establish whether the length of time feedback devices were used in training related to final CPR quality.[13] This was a randomized, controlled manikin study.[13] Even though participants and instructors knew how much time was spent with the feedback device, the study endpoints and statistical analyses were blinded.

The study took place at two training centers in Italy. Researchers recruited participants via newspaper ads and social media to join a free BLS/AED course.[13] Participants were included if they were over the age of 18 and had no previous CPR training. Basic demographics of participants including gender, age, weight, and height were collected.[13] The researchers recruited a total of 450 participants.

Participants were randomly assigned to one of three groups. Each group consisted of 150 participants and were labeled as the following: group no feedback (NF), group short feedback (SF), and group long feedback (LF). [13] Each group attended the same five-hour BLS/AED courses; the only difference was how long each group had with feedback devices. [13] Each five-hour course involved one hour of theory and four hours of practice. The only difference in the three groups was the amount of time each group spent training with the feedback devices. The NF course consisted of basic BLS/AED training without any training with a feedback device. The SF course consisted of BLS/AED course with one minute of real-time visual feedback with the manikin. Finally, the LF course entailed the same BLS/AED course as the previously two mentioned courses but had 10 minutes of practicing with a real-time visual feedback manikin.[13] All courses were performed according to the 2010 International Liaison Committee on Resuscitation (ILCOR) guidelines. At the end of each course, researchers recorded a one-minute bout of compression-only CPR. This one-minute session included the same manikin and software but did not include any visual feedback for the participant.[13]

The researchers conducted an ANOVA test with a Fishers' least significant difference correction to assess post-hoc comparisons.[13] All of the variables were calculated with a 95% confidence interval with an alpha of .05. Researchers found data significantly reflected a positive effect with the use of the feedback devices. Between all three groups, percentage of compressions with correct depth ($p = .012$); percentage of compressions with complete chest recoil ($p < .001$); percentage of compressions with correct hand position ($p < .001$); and, total CPR score ($p < .001$) were significantly different.[13] The only category where there was no significance was compression rate. Groups SF and LF both received time with feedback devices, even though their times with the devices varied, the data showed no significant differences in any of the parameters.

The results of this study support the AHA's 2017 update that feedback devices can help students master CPR. Although the SF group and LF groups both spent time with feedback devices, it showed there was no difference in overall CPR scores whether groups spent one minute or 10 with the devices. Based on the results, researchers determined only one minute of real-time visual feedback was needed to improve overall CPR quality.[13] These results have implications for future CPR training and how those who certify individuals teach. The devices demonstrate the capability to give real-life measurements for multiple parameters. Even though the results from this study seem to be in favor of the feedback devices, further research incorporating real-time visual feedback during CPR training should be conducted to make accurate inferences about the impact of the devices.

Likewise, a different study[90] conducted found similar results to the previously mentioned study[13] regarding the efficiency of feedback devices. Tanaka et al.[90] aimed to determine if quality cardiopulmonary resuscitation (QCPR) classroom training led to higher quality chest compressions compared to standard CPR training.[90] Feedback devices are effective in teaching the untrained layperson; however, the devices are not often available or feasible to use in large groups.[90] To combat this challenge, Laerdal Medical (Stavanger, Norway) introduced the QCPR classroom concept. The QCPR classroom concept aims to effectively teach large groups of individuals with real-time audiovisual feedback projected onto a screen so all individuals can see their progress.

Researchers recruited 642 participants who were enrolled in Heart Saver Japan CPR training. To be included in the study, participants had to be over the age of 15. Participants were excluded if they had an upper extremity injury in the past six months and had been working as a healthcare professional in a setting where CPR is regularly administered.[90] Researchers primarily focused on compression depth, rate, adequate depth, and adequate recoil as outcomes of the study.[90] The outcomes were assessed one minute prior to training and immediately after training.

Participants were randomly grouped into 18 sessions. Each sessions were randomly assigned as control or intervention (QCPR classroom).[90] The instructors for these sessions had over five years of experience teaching CPR and had previous history of working in healthcare. Within the sessions, participants were trained in basic life support (BLS) skills, which included CPR and proper use of an automated external defibrillator (AED) in accordance to the Japan Resuscitation Council 2015 guidelines.[90] All participants were taught compression-only CPR.

Each training began with a PowerPoint presentation followed by an instructor-led lecture. Following the presentation and lecture, participants began CPR psychomotor practice. Objective and subjective feedback were given from the instructor based on the real-time feedback in the QCPR sessions.[90] Through the feedback, participants were able to correct their performance and watch in real-time how their overall performance changed by looking at the feedback displayed on the screen. The control group had the instructor hand clap to help keep them on track for proper compression rate because there was no feedback device available.[90]

Out of the 642 participants, only 497 were eligible for analysis. A total of 145 participants were excluded because they did not meet the inclusion criteria. Researchers collected basic demographics such as age, weight, gender, and previous CPR training. A Q-Q plot was performed to confirm normal distributions and homogeneity of variables. Recoil and adequate depth were calculated as percentages.[90] A paired *t*-test and McNemar test were conducted to analyze the difference between pre-training and post-training measurements.[90] To compare the groups for both pre-training and post-training, Welch's t-test and $x^2$ tests were performed.[90]

Overall, participants in the QCPR classroom performed better on all almost every component of CPR when compared to the control group. Those in the QCPR classroom had a mean compression depth of 59.5±7.9 mm while the control groups' mean compression depth was 56.1±9.8 mm.[90] Adequate depth was significantly better in the QCPR classroom compared to the control group ($p < .001$).[90] The QCPR class increased their overall depth by 39%, where the control group improved their overall depth by 20%.[90] There was also a statistically significant difference in chest recoil between the two groups. The control group showed a 2.7% increase, and the QCPR group showed a 22.6% increase of percentage of recoil ($p <.001$).[90] Average chest compression rate was the only component where both the QCPR and control groups were similar. Both groups were able to keep their average compressions at a rate of 100-120 chest compressions/minute. The meaningful results impact the future of CPR training and how feedback devices can increase certain CPR parameters to improve overall CPR quality.

The research conducted by Baldi et al.[13] and Tanaka et al.[90] show promising data regarding teaching and retaining CPR parameters for future trainings. The data shows an increase in overall CPR performance. If laypersons can visualize the quality of their CPR, it could make them feel more confident and more likely to intervene if an OHCA occurs near them. The implementation of feedback devices during CPR certifications has the possibility to increase the rate of individuals who initiate bystander CPR on victims experiencing sudden cardiac arrest.

## 2.3. Coaches

### 2.3.1. Introduction

Although the risk of sport related sudden cardiac arrest (SCA) and sudden cardiac death (SCD) is relatively low,[2,24,26] there is still a threat associated with sport participation. Medical professionals such as athletic trainers are not always present at sport events,[92] thus leaving coaches as the first line of defense for cardiac emergencies. The lack of trained health care providers can result in delayed care. Alarmingly, this delayed care can result in a 7-10% decrease in survival per minute in the absence of CPR.[17] In the case of pediatric SCAs (< 18 years,) only 11.4% survive to hospital discharge.[93] At the high school level, coaches are considered first on the scene for up to one third of SCAs.[3] However, there is little data indicating how many coaches currently hold a CPR certification and can perform high-quality CPR.[3] Furthermore, there is presently no nationwide policy mandating coaches be CPR certified at any level of competiton.[3] This lack of mandated CPR certification puts sport participants in danger. It is essential coaches at all levels are trained and feel confident in performing high-quality CPR to increase chance of survival in case of SCA.

### 2.3.2. Impact

Minimal research has been conducted on coaches' ability to perform high-quality CPR.[3,94] Most of the available research has examined CPR certification status of coaches with the primary population of focus being high school coaches.[3,94] However, there is a lack of research regarding coaches at other levels of competition. The scarcity of research makes it difficult to determine how many coaches at any level hold a current CPR certification and can properly administer CPR.

In an attempt to determine the true number of high school coaches in the state of Wisconsin that were CPR certified, researchers performed a prospective web-based survey of high school athletic directors.[3] In Wisconsin, the status of coaches who were CPR certified was unknown, as there is not a state requirement for coaches to be CPR certified.[3] Additionally, the certification is not mandated by the Wisconsin Interscholastic Athletic Association (WIAA).[3] Researchers set out to determine who was considered to be first on the scene for cardiac emergencies. Additionally, researchers sought to establish the overall attitude about a state-wide CPR mandate for high school coaches.

The researchers emailed a 16-item survey adapted from pediatric sports medicine physicians from the University of Wisconsin.[3] All email addresses were obtained from the WIAA database and sent to athletic directors across the state. Questions centered around the presence of an emergency action plan (EAP), plans for a SCA on campus, and CPR certification of coaches.[3] Several questions used a Likert-type scale for responses. A total of 503 athletic directors were contacted and follow-up emails were sent after two weeks.

A total of 243 athletic directors responded to the survey equating to a response rate of 48%.[3] In 78% of cases, a coach was determined to be the primary responder to a collapse.[3] Twenty-one percent of athletic directors estimated nine minutes until EMS arrival, while a majority of athletic directors estimated four to nine minutes until EMS arrival. This estimation is lower than the national average EMS response time of eight minutes and 59 seconds in an urban area.[95]

Currently, only 32% of high schools in Wisconsin require CPR certification.[3] Athletic directors estimated 40-60% of their coaches possessed current CPR certification.[3] Even though athletic directors acknowledged some coaches were CPR certified, only 55% agreed coaches should be required by law to maintain a current CPR certifcation.[3] A majority (86%) of athletic directors think coaches should be certified but do not support a legal mandate.[3] This lack of mandated CPR certification for coaches leaves sports participation in a perilous position in the event of SCA.

In the 2011-2012 school year, Wisconsin had over 190,000 students enrolled in high school.[3] Based off enrollment, researchers estimated an annual incidence of 4.4/100,000 SCA cases in this age group. These data suggest Wisconsin could expect eight or nine collapses per year.[3] Interestingly, in the state of Wisconsin there is a 78% chance a coach will be first on the scene for cardiac emergencies at the high school level. This number is greater than the reported value of coaches being the first responder for up to one-third of high school collapses.[3,96] The information indicates coaches play more of a role in resuscitation efforts than originally thought for individuals who experienced SCA than previously thought.[3]

In another investigation of high school coaches, researchers set out to determine coaches' knowledge about basic first aid, CPR, and AED use.[94] In a previous study, it was found at the time of data collection less than 30% of coaches held a current CPR certification.[97] Furthermore, there is even less known about how much knowledge coaches have about proper CPR administration. Only 22% of high school associations require a current CPR certification for all coaches.[94]

Researchers set out to recruit high school coaches during registration at an annual coaches' conference in a Midwest state.[94] Coaches were included if they were over the age of 18 and currently coached at the high school level. A sample of 90 coaches were recruited to take part in the survey. At the time of the survey, 91% of coaches held a current CPR certification,[94] which opposes the findings of the aforementioned study where it was reported that only 40-60% of Wisconsin high school coaches held a current CPR certification.[3] The survey consisted of three sections. The first section involved eight questions covering coaching certifications. The second section was a 10-question demographic section. The third and final section entailed 20 multiple choice questions about knowledge of CPR/AED, asthma, and heat related illness.[94] These questions were adapted from the American Heart Association (AHA) and the American Red Cross (ARC).

A Fischer's Exact test was conducted to examine the relationship between years of coaching experience and coaches' knowledge of asthma, heat related illness, AED, and CPR.[94] An independent samples *t*-test was used to compare coaches' level of education in relation to the scores of the four topic areas. This was done to avoid grouping results into one category and to be able to evaluate each question to see where coaches were lacking in knowledge.

The researchers found regardless of the number of years an individual had coached, they did not answer questions about CPR correctly.[94] Two questions about CPR knowledge in regards to proper chest compression depth and correct compression to ventilation ratio were both answered incorrectly ($p = .039$, and $p = .047$, respectively).[94] These two questions asked participants the proper depth of chest compressions when performing CPR on a child and the correct compression to ventilation ratio when performing one resucer child CPR.[94] There was also a statistically significant difference in relation to CPR knowledge and coaches level of education.[94] Coaches who had a Master's degree ([(M=.98, SD=.158); $t(56)=-2.476$, $p =.016$]) answered two questions with less variance versus those with Bachelor's degree (M=.81, SD=.394).[94] Although two out of the 20 multiple choice questions were statistically significant in relation to coaches' education, there was not enough information to make inferences about a coach's education level and knowledge of CPR, AEDs, and first aid.[94]

Although 91% of coaches who participated in this study were CPR certified and had gone through formal training, they lacked basic knowledge about CPR. This puts youth at risk for poor outcomes in the event of a cardiac emergency with no medical professional on campus. In 2009, only 42% of high schools employed athletic trainers, who are trained in emergency care.[7] Because the survival rate for youth in SCA is relatively low, it is imperative for coaches to be trained and stay current with the AHA's recommendations released every five years.[93] Implementing CPR mandates as part of coach's education is crucial as more and more students participate in athletics.[94]

Coaches are responsible for individuals who are at risk for cardiac emergencies.[1–3] However, there has been minimal research to determine if coaches are prepared for these emergencies and can actually perform life-saving interventions such as CPR.[3,94] The lack of mandates for CPR certification of coaches is of concern due to the likelihood of coaches being first on the scene of a cardiac emergency.[3,96] The lack of knowledge and research about coaches illustrates the potential for dangerous situations like death in the pediatric athletic community. Further research incorporating psychomotor practice and exploring coaches outside of the high school level is necessary to make accurate inferences about coaches who hold current CPR certification and can properly perform high-quality CPR.

# 3. METHODOLOGY

## 3.1. Purpose of Study

Sudden cardiac arrest (SCA) is one of the leading causes of death in the United States with a mortality rate for out-of-hospital cardiac arrest (OHCA) approximately 90% even with intervention from emergency medical services.[4] In 2009, only 42% of high schools employed an athletic trainer.[7] Thus, coaches are often the first on the scene of a medical emergency. Coaches are considered lay rescuers; therefore, they are not required to perform ventilations during cardiopulmonary resuscitation (CPR) administration.[4] Instead, the American Heart Association (AHA) recommends compression-only CPR for those individuals with no formal health care responsibilites.[4]

Although research evaluating the relationship between self-efficacy and CPR performance is somewhat limited and has mixed outcomes,[10,12,18,87,98] there is evidence suggesting higher self-efficacy may have a positive impact on bystanders' overall performance.[18,19] Therefore, it is essential that coaches feel confident in their ability to perform high-quality CPR. Existing research has demonstrated that when participants receive feedback following CPR intervention in mock scenarios, they report increased self-efficacy in follow-up evaluations of CPR.[99] Additionally, research supports that verbal and visual feedback during CPR performance increases overall CPR performance.[4,13,99100] Further research is needed to determine if deliberate feedback and methods (such as different types of feedback and increased practice times) to increase self-efficacy should be incorporated into coach's CPR certification and training.

Based on this information, the primary purpose of this research study was to investigate the relationship between self-efficacy and CPR quality in coaches with the use of a self-efficacy survey and CPR simulation manikins. A secondary purpose was to determine if deliberate feedback increases coaches' CPR performance and self-efficacy. This study was completed to answer the following questions:

Q1: What percentage of coaches achieved satisfactory performance (according to the 2020 AHA CPR Guidelines) on compression rate, depth, and recoil?

Q2: What is the relationship between coaches' self-efficacy and CPR performance?

Q3: To what degree does self-efficacy predict CPR performance?

Q4: To what degree does deliberate feedback increase CPR performance and self-efficacy?

### 3.2. Participants

A convenience sample of 20 middle school, high school, college, or club coaches in the states of North Dakota and Minnesota were recruited through email and word-of-mouth. Inclusion criteria included current coaches and assistant coaches for any sport at the middle school, high school, college, or club level. Participants were not required to have current CPR/Basic life support (BLS) certification, as there is currently no national requirement for coaches to be CPR/BLS certified.[3] Exclusion criteria consisted of any current systemic or musculoskeletal conditions, which may impede a participant's ability to perform high-quality CPR at the time of testing. Participants were compensated $10 for their participation in the study. Informed verbal and written consent were obtained from each subject before enrollment. Baseline demographic data was collected by a participant demographic form.

## 3.3. Equipment and Instruments

### 3.3.1. Resusci Anne QCPR Manikin

A Resusci Anne QCPR Manikin (Laerdal Medical, Stavanger, Norway) was used to measure CPR performance. Ventilations were not incorporated in the algorithm because, according to the AHA, lay rescuers should administer compression-only CPR.[5] The manikin was equipped with the Laerdal SkillReporter software (Stavanger, Norway), which evaluates components of CPR including hand position, chest compression rate, chest compression depth, and chest recoil. At the end of each CPR session, the software calculated an overall QCPR score ranging from 0% to 100% to give a measure of overall CPR performance.

### 3.3.2. CPR Self-Efficacy Assessment

The participants completed a self-efficacy questionnaire developed by the researchers to assess participants' confidence in performing CPR. The eight-item questionnaire was based off the Basic Resuscitation Skills Self-Efficacy Scale (BRS-SES) created by Hernandez-Padilla et al.[89] and altered to fit the needs of the participant population of coaches (lay rescuers) by removing any questions regarding administration of ventilations. The original questionnaire was tested for validity and reliability by the researchers. The eight-item questionnaire required participants to use a Likert-type scale to rate themselves from least confident to very confident in their ability to perform specific aspects of CPR according to the 2020 AHA CPR guidelines.

### 3.3.3. CPR Deliberate Feedback Questionnaire

Participants completed a deliberate feedback questionnaire developed by the researchers to assess if deliberate feedback and coaching increases participants'confidence in performing CPR. The five-item questionnaire was based off of secondary outcomes from a research study by Schober et al.[101] and altered to feed the needs of the participant population of coaches (lay rescuers). The researchers did not mention any testing for reliability or validity for the original questionnaire, however they acknowledged this as a limitation in the study.[101] The five-item questionnaire requires participants to use a Likert-type scale to rate themselves on how helpful they perceived deliberate feedback and instruction.

### 3.4. Procedures

Prior to data collection, the study was approved by the North Dakota State University Institutional Review Board. Participants were recruited through word-of-mouth and email. Once the participants arrived at the site of data collection, they were given an informed consent form to read and sign. If the participants had any questions about the study, a member of the research team was available to answer their questions. Next, the participants completed a demographic information sheet that was used to collect data such as age, biological sex, sport coached, years of coaching experience, and if they were currently CPR certified. The demographic information provided by the participants was used during data analysis. Lastly, the participants completed the CPR self-efficacy questionnaire included to assess participants' baseline confidence to perform CPR. The six-point, Likert-type scale was explained to the participants and clarified if needed.

After all paperwork was completed and any additional questions answered, participants completed a baseline assessment of CPR performance for five minutes of compression-only CPR using a Resusci Anne QCPR manikin. Participants were asked to perform compression-only CPR in accordance with the 2020 AHA guidelines: compression rate of 100-120 per minute, a compression depth of greater than or equal to 5 cm but no more than 6 cm, and full chest recoil.[4] During this first five minutes of compression-only CPR, no visual or auditory feedback was given from the Laderdal SkillReporter software or the research team to avoid any changes in performance based feedback.

At the end of five minutes, the participants were given an overall QCPR score as well as scores for each of the aforementioned components. The researcher explained the meaning of the scores and how overall performance could be improved. After this, participants took a five-minute break. At the conclusion of the five-minute break, participants practiced compression-only CPR for one-minute. During this one-minute bout, participants received deliberate feedback from the Laderal SkillReporter software, which allowed participants to make necessary adjustments to CPR performance in real time. This is important, as research suggests real-time, deliberate feedback improves acquisition and retention of CPR psychomotor skills.[4,13] Participants were also able to ask questions while they completed their one-minute practice session. The researcher or research assistant was able to help interpret the deliberate feedback while the participant was performing the compression-only CPR. After the one-minute bout of deliberate feedback, participants took a two-minute break. During this break, the participant completed the deliberate feedback questionnaire and the CPR self-efficacy questionnaire for a second time.

After completion of the two-minute break and completion of the questionnaires, participants then completed another five-minute bout of compression-only CPR. Again, the participant was instructed to follow the 2020 AHA CPR guidelines described earlier. Participants did not receive any deliberate feedback while performing the second, five-minute bout of compression-only CPR, thereby mimicking a real-life scenario where the rescuer would not have immediate feedback.

At the conclusion of the assessment, the participant was given their second overall QCPR score from their second five-minute bout of compression-only CPR. The data were saved from each session with a deidentified number in the system. For each session, the following values were recorded: overall QCPR score, hand placement, compression rate percentage, mean compression rate, compression depth percentage, mean compression depth, mean recoil percentage, and total number of compressions. Participants were issued $10 as compensation for their cooperation in the study.

### 3.5. Statistical Analysis

All statistical analyses were completed vis IBM SPSS statistics software version 25.0 (IBM, Armony, New York). First, a *t*-test was calculated to compare the CPR self-efficacy questionnaire results before and after the CPR assessment. Basic descriptive statistics were used to analyze the percentage of coaches who achieved a satisfactory performance (according to the 2020 AHA CPR guidelines) on compression rate, depth, hand placement, and recoil. A linear regression model was utilized to assess if self-efficacy is related to CPR performance and to what degree other demographics like biological sex, CPR certification, and years coaching were related to CPR self-efficacy. Statistical significance for all statistical analyses was set to a *P* value of $<0.05$.

### 3.6. Conclusion

The primary purpose of this research was to investigate the relationship between self-efficacy and cardiopulmonary resuscitation (CPR) quality in coaches. Additionally, this study sought to determine whether deliberate feedback increases coaches' CPR performance and self-efficacy. Although the employment of athletic trainers in the secondary setting is increasing, there are still barriers to employing athletic trainers in many schools.[7] When an athletic trainer is not present, coaches are the first line of defense in the event of a cardiac emergency; this it is imperative that coaches are proficient in administration of quality CPR. As a result, determining coaches' ability to perform high-quality CPR is essential to the creation of future requirements for coaches to obtain CPR certification. Furthermore, assessing the efficacy of deliberate feedback of CPR skills can help determine best-practices for future CPR courses for coaches.

# 4. MANUSCRIPT

## 4.1. Abstract

[Study Design]: Mixed Methods

[Background]: For coaches to be able to provide high-quality CPR, factors that impact CPR performance must be identified to improve patient outcomes attributed to sudden cardiac arrest. Though self-efficacy is one factor that has been shown to impact performance in healthcare providers, there have been no studies involving coaches.

[Objectives]: The primary purpose of this study was to determine if coaches could properly perform high-quality CPR.

[Methods]: Twenty coaches ($32 \pm 11.2$ years) with experience ranging from 0.25-32 years volunteered. Participants completed an eight-item self-efficacy questionnaire. Upon completion of the questionnaire participants performed five minutes of compression-only CPR in accordance with the 2020 AHA guidelines without any audio or visual feedback. Participants had one minute with audio and visual feedback and filled out for the second time the same self-efficacy questionnaire and a five-item deliberate feedback questionnaire. Participants then performed for a second and final five minute bout of CPR with no feedback. CPR was performed on a Resusci Anne® QCPR Manikin, and objective measures of CPR quality were measured via Laerdal SkillReporter Software. A *t*-test was calculated to compare the CPR self-efficacy questionnaire results before and after the CPR assessment. Basic descriptive statistics were used to analyze the percentage of coaches who achieved a satisfactory performance on compression rate, depth, hand placement, and recoil. A linear regression model was utilized to assess if self-efficacy is related to CPR performance and to what degree other demographics like biological sex, CPR certification, and years coaching were related to CPR self-efficacy.

[Results]: Overall, after the use of deliberate feedback device there was strong, positive relationship between self-efficacy and quality of CPR performance after feedback from the first five minutes and one minute of deliberate feedback. After the use of deliberate feedback devices there was a positive correlation in four of the CPR parameters which included overall CPR score, depth, compression/min, and rate. Additionally, linear regression was used to determine if scores on the self-efficacy and deliberate feedback surveys were significant predictors of CPR performance. The model was not statistically significant (F[2, 16]=2.105, $p$=.140). Results of a paired samples $t$-test revealed a statistically significant increase in self-efficacy from pre- to post-deliberate feedback ($t$[19]=-4.934, $p$<.001).

[Conclusion]: Prior to any deliberate feedback, coaches were not able to perform high-quality CPR. However, with the use of feedback devices coaches were able to increase their overall CPR score, additionally there was a strong relationship between self-efficacy and CPR performance. Further research involving larger sample sizes must be conducted to determine whether the relationship CPR self-efficacy, CPR performance, and deliberate feedback in coaches is significant enough to warrant updated guidelines and changes to CPR education.

[Level of Evidence]: Quality Improvement, level 2b

[Key Words]: Cardiopulmonary resuscitation, coaches, self-efficacy, deliberate feedback

## 4.2. Introduction

Sudden cardiac arrest (SCA) is the most common cause of sudden cardiac death (SCD) in young athletes.[1,26] Within the pediatric population, the estimated incidence of SCD ranges from one in 40,000 to one in 80,000.[6] During SCA, prompt initiation of cardiopulmonary resuscitation (CPR) by a healthcare provider or layperson is critical to a patient's odds of survival.[4] The absence of health care providers in athletic settings often leaves coaches as the primary responder in competitive or recreational athletics. In fact, coaches have been reported as emergency responders for 33% to 78% of cardiac emergencies in high schools.[3]

Currently within the United States, there is no national mandate requiring coaches at any level to be CPR certified.[3] The lack of mandates for CPR certification of coaches is of concern due to the likelihood of coaches being first on the scene of a cardiac emergency.[3,96] The scarcity of research makes it difficult to determine how many coaches at any level hold a current CPR certification. Additionally, it also makes it challenging to know if coaches who are certified can properly administer CPR. It is essential coaches at all levels are trained and feel confident in performing high-quality CPR to increase chances of survival.

Beyond the basic skillset of CPR, emergency situations require a sense of confidence to provide a medical intervention.[87] An individual's perceived self-efficacy, or confidence to perform effective skills/actions, has been identified as an intrinsic factor that could contribute to overall CPR performance.[10] The minimal research available pertaining to self-efficacy assesses the relationship of the psychological factor in health care providers.[10,87,88] Researchers have found in nursing students that rescuer confidence is possibly gained through psychomotor practice.[10] Thus, research specific to coaches is critical to making recommendations to the American Heart Association (AHA) and the American Red Cross (ARC) about best practices and educational interventions.

Throughout the years, different CPR feedback devices have been developed and implemented into education sessions as a resource for participants to gauge whether they can correctly perform CPR. Previously, the use of feedback devices has indicated an increase in overall CPR performance within healthcare providers.[13,90] In 2017 the (AHA) introduced guidelines requiring the use of feedback devices in all adult CPR training courses.[91] This was in part due to research suggesting instructor assessment of chest compression quality is not accurate.[91] The use feedback devices during CPR trainings can provide a strong foundation for CPR psychomotor skill acquisition and retention.[13,90,91] Researchers have found spending as a little as one minute with feedback devices can significantly improve overall CPR quality.[13]

Based on the myriad of components that can affect CPR performance, the purpose of this study was threefold. First, to determine what percentage of coaches achieved satisfactory performance on compression rate, depth, and recoil. Second, to investigate the relation between self-efficacy and CPR quality in coaches. Finally, to ascertain what degree deliberate feedback effects CPR performance and self-efficacy.

## 4.3. Methods

### 4.3.1. Participants

A convenience sample of 20 middle school, high school, college, or club coaches (Mean age = 32.4) who are currently employed as coaches were recruited through email and word-of-mouth throughout North Dakota and Minnesota. Participants were not required to be Cardiopulmonary Resuscitation/Basic Life Support (CPR/BLS) certified at the time of data collection. Exclusion criteria included any current systemic or musculoskeletal conditions, which may have impeded a participant's ability to perform high-quality CPR at the time of testing. Informed written and verbal consent were obtained from each subject prior to enrollment.

### 4.3.2. Procedures

Prior to the start of data collection, this study was approved by the university's institutional review board. Upon arrival to data collection, baseline demographic data were collected by a participant demographic form. Next, participants were asked to complete an eight-item CPR self-efficacy questionnaire. The questionnaire was conducted with the use of the Basic

Resuscitation Skills Self-Efficacy Scale (BRS-SES) originally published by Hernandez-Padilla et al.[89] The eight-item questionnaire asked participants to evaluate their confidence when performing specific aspects of CPR during emergency situations in accordance with the 2020 American Heart Association (AHA) guidelines. Participants responded to each optimistically phrased prompt using a six-point, Likert-type scale ranging from "Strongly Disagree" to "Strongly Agree".

Upon completion of paperwork and demographic collection, participants began their first five minutes of compression-only CPR. During this session, no verbal or visual feedback was given to participants. All CPR sessions were performed in accordance with the 2020 AHA CPR guidelines on a Resusci Anne® QCPR manikin (Laederal Medical, Stavanger, Norway). Upon completion of the first bout of compression-only CPR, participants were given an overall QCPR score followed by a five-minute break. For each session the following values were recorded: overall QCPR score, hand placement, compression rate percentage, mean compression rate, compression depth percentage, mean compression depth, mean recoil percentage, and total number of compressions. During a one-minute educational session, participants received deliberate feedback from the Laderal SkillReporter software, which allowed participants to make necessary adjustments to CPR performance in real time. Additionally, during this one-minute bout, participants were able to ask questions and receive feedback from the researchers.

At the conclusion of the one-minute practice with audio and visual feedback, participants took a two-minute break. During this break participants completed the CPR Self-Efficacy questionnaire for a second time and a five-item deliberate feedback questionnaire. The deliberate feedback questionnaire was conducted as a secondary outcome originally published by Schober et al.[101] The five-item questionnaire assessed whether deliberate feedback and teaching increased participants’ confidence in performing CPR. Participants responded to each optimistically phrased prompt using a six-point Likert-type scale ranging from “Strongly Disagree” to “Strongly Agree”.

Upon the completion of the two-minute break, participants began their second and final bout of five-minute compression-only CPR. Again, participants were instructed to perform CPR while adhering to the 2020 AHA guidelines. Similar to the first five-minute bout, participants did not receive any deliberate feedback during their CPR administration. At the conclusion of the assessment, the participant was given their second overall QCPR score from their second five-minute bout of compression-only CPR.

**4.3.3. Statistical Analysis**

All statistical analyses were completed vis IBM SPSS statistics software version 25.0 (IBM, Armony, New York). First, an alpha was created to calculate the CPR self-efficacy questionnaire for internal reliably. Next, a *t*-test was calculated to compare the CPR self-efficacy questionnaire results before and after the CPR assessment. Basic descriptive statistics were used to analyze the percentage of coaches who achieved a satisfactory performance (according to the 2020 AHA CPR guidelines) on compression rate, depth, hand placement, and recoil. A linear regression model was utilized to assess if self-efficacy is related to CPR performance and to what degree other demographics like biological sex, CPR certification, and years coaching were related to CPR self-efficacy. Statistical significance for all statistical analyses was set to a $P$ value of $<0.05$.

**4.3.4. Results**

Twenty participants completed all surveys and CPR trials; demographic data are summarized in Table 1. Participants ranged widely in terms of age and coaching experience, and approximately two-thirds of the sample was CPR certified. Additionally, mean scores on the self-efficacy and deliberate questionnaires are presented in Table 2. Descriptive statistics were calculated for the five performance variables during each CPR trial, these values are presented in Table 3.

**Table 8.** Demographic Data

| | **Categorical Variables** | |
|---|---|---|
| Biological Sex | Male | 5 |
| | Female | 15 |
| CPR Certification | Yes | 13 |
| | No | 7 |
| Setting | High School | 4 |
| | College | 10 |
| | Club | 6 |
| | **Continuous Variables** | |
| Age | Mean (SD) | 32.4 (11.2) |
| | Range | 20-54 |
| Weight | Mean (SD) | 203.6 (48.6) |
| | Range | 125-290 |
| Years Coaching | Mean (SD) | 10.6 (10.4) |
| | Range | 0.25-32 |

**Table 9.** Average Overall CPR Performance and Questionnaire Results

| **Trial** | **Mean Score (SD)** | **Range** |
|---|---|---|
| Pre-DF Self-Efficacy | 33.6 (7.6) | 8-41 |
| Post-DF Self-Efficacy | 40.8 (4.8) | 30-47 |
| DF Questionnaire | 26.1 (2.53) | 20-30 |

Abbreviations: DF, Deliberate Feedback

**Table 10.** Descriptive Statistics of Performance

| Performance Variable | Pre-DF (SD) | DF Session (SD) | Post-DF (SD) |
|---|---|---|---|
| Overall QCPR Score | 45.2 (40.25) | 89.55 (14.75) | 81.5 (22.90) |
| Depth | 42.45 (39.99) | 88.35 (18.05) | 73.25 (30.47) |
| Recoil | 44.15 (33.90) | 77.1 (26.11) | 67.95 (33.08) |
| Hand Position | 78.15 (36.28) | 94.45 (13.54) | 96.20 (7.84) |
| Rate | 43.55 (40.35) | 79.15 (24.54) | 74.55 (31.76) |

Abbreviations: DF, Deliberate Feedback

The eight items of the CPR self-efficacy questionnaire as well as the five items of the deliberate feedback questionnaire were tested for internal reliability. For both administrations of the self-efficacy survey, adequate reliability was observed (pre-deliberate feedback α=.930, post-deliberate feedback α=.850). Reliability of the deliberate feedback survey was questionable with a Chronbach's alpha value of α=.627.

Results of a paired samples *t*-test revealed a statistically significant increase in self-efficacy from pre- to post-deliberate feedback (*t*[19]=-4.934, *p*<.001). Additionally, a paired samples *t*-test was used to assess changes in overall CPR performance from pre- to post-deliberate feedback. This analysis also revealed a significant difference with the overall QCPR score increasing significantly post-deliberate feedback (*t*[19]=-3.853, *p*=.001). Thus, self-perceptions of abilities were positively affected by participation in the study.

The Laerdal SkillReporter software provided assessment data in the form of percent of adequate performance on six variables: overall performance, depth, recoil, hand position, and rate. Tables 4 and 5 present correlations computed between the scores of self-reported self-efficacy values for CPR performance and each of the six performance measures. Pre-deliberate feedback, one correlation is statistically significant at the 5% level, and one at the 10% level. Moreover, post-deliberate feedback, three correlations were significant at the 5% level, and one was significant at the 10% level. In all cases, the statistically significant correlations are positive, indicating that greater self-efficacy scores are related to increase CPR performance, primarily after receiving practice with deliberate feedback.

**Table 11.** Correlations With Pre-deliberate Feedback Self-efficacy and Pre-deliberate Feedback CPR Performance

| Variable | Correlation | Significance |
|---|---|---|
| Overall | 0.386 | *p*=.093* |
| Depth | 0.110 | *p*=.645 |
| Recoil | 0.088 | *p*=.713 |
| Hand Position | 0.260 | *p*=.269 |
| Rate | 0.483 | *p*=.031** |

**significant at α=.05
*significant at α=.10

**Table 12.** Correlations With Post-deliberate Feedback Self-efficacy and Post-deliberate Feedback CPR Performance

| Variable | Correlation | Significance |
|---|---|---|
| Overall | 0.469 | *p*=.037** |
| Depth | 0.482 | *p*=.031** |
| Recoil | 0.457 | *p*=.043** |
| Hand Position | -0.031 | *p*=.896 |
| Rate | 0.414 | *p*=.070* |

**significant at α=.05
*significant at α=.10

Additionally, linear regression was used to determine if scores on the self-efficacy and deliberate feedback surveys were significant predictors of CPR performance. The model was not statistically significant ($F[2, 16]=2.105$, $p$=.140).

As a whole, these results indicate a weak, positive relationship between self-efficacy and CPR performance before participants received any type of feedback. However, after receiving feedback on the initial five-minutes of compression-only CPR as well as completion of a one-minute bout of CPR with deliberate feedback, a strong, positive relationship between self-efficacy and quality of CPR performance was observed.

## 4.4. Discussion

The primary purpose of the current study was to determine what percentage of coaches achieved satisfactory performance on hands-only CPR variables. We also sought to evaluate a possible relationship between self-efficacy and CPR quality in coaches. Finally, we aimed to determine to what degree deliberate feedback effects CPR performance and self-efficacy. The available research regarding coaches' ability to properly perform CPR is scarce, thus this study was aimed at attaining evidence for future use in the development of CPR education guidelines for coaches. The results of the present study study indicate that coaches are unable to perform high-quality CPR without the use of a deliberate feedback intervention.

The five parameters of CPR tested within the five minutes of compression-only CPR included overall CPR score, depth, chest recoil, hand placement, and compression rate. The participants in this study had a wide range of results when performing the aforementioned parameters prior to a deliberate feedback intervention. In a study by Steill et al.[70] it was noted that participants struggled to reach the correct compression depth of 38-55 mm. Their participants on average reached a depth of 41mm. Our participants had a difficult time reaching a compression depth of ≥5 but ≤6 cm. The AHA's recommendation of 100-120 compressions/minute was supported by Idris et al.[69] It was noted in their study that patients who received compressions at a rate of 100-120 compressions/minute had a greater chance to hospital discharge. Within our study, some individuals found it challenging and demanding to keep up with the recommendation of 100-120 compressions/minute. The average score prior to any feedback for compressions/minute was 43.55 out of 100.

While our study was the first to examine the relationship between self-efficacy and CPR performance in coaches, we found similar results from research examining the relationship in healthcare professionals.[10,12] Studies by Gonzi et al.[12] and Roh et al.[10] suggested a positive relationship between participant self-efficacy and overall CPR performance within doctors and nurses. In the present study, similar to Gonzi et al.[12] and Roh et al.[10], in the present study a weak positive relationship was noted between self-efficacy and CPR performance, but a positive relationship was revealed between self-efficacy and CPR performance. This correlation suggests that there may be a link between self-efficacy and CPR performance in coaches similar to the association found in health care providers.[10,12] Conversely to previously mentioned studies[12,87], Lammert et al.[88] found a small negative relationship between CPR performance and self-efficacy within certified athletic trainers.

In 2015 the updated guidelines released by the AHA it was suggested to use audiovisual feedback devices for adult CPR training, and in 2017 the AHA went one step further and mandated the use of feedback devices in CPR courses.[90] This important research suggests real-time, deliberate feedback improves acquisition and retention of CPR psychomotor skills.[4,13] Research conducted by Baldi et al.[13] and Tanaka et al.[90] show promising data regarding teaching and retaining CPR skills. In both of the aforementioned studies, participants who used audiovisual feedback devices improved in chest recoil, hand position, chest refraction, and overall CPR.[13,90] Similarly, in the current study we found a statistically significant increase in overall CPR performance from pre- to post-deliberate feedback (p= .001). Furthermore, Baldi et al.[13] suggested that regardless of the time spent with feedback devices, participants scores and CPR parameters still increased. In the current study, participants received one minute of practice with audiovisual feedback, which resulted in significant skill improvement. Thus, it can be concluded that short durations of deliberate feedback practice are sufficient to create meaningful improvements in CPR performance.

The true number of coaches who maintain a current CPR certification across the United States is unknown. A study by Harer et al.[3] found that in the state of Wisconsin, 40-60% of high school coaches were CPR certified. This aligns closely with the demographics of the population of coaches in the present study where approximately 65% of coaches reported being CPR certified. However, in a different study examining CPR certification status of coaches, researchers reported that 91% of high school coaches from a Midwest region were CPR certifed.[94] The present study included coaches at the middle school, high school, college, and club level, which included a different participant population compared the previously mentioned studies.

This study was not without limitations. Participants performed CPR in a controlled environment on a Resusci Anne® QCPR Manikin rather than on an actual patient in a sports setting. The lack of external factors or stressors could have resulted in participants feeling as though CPR was easier to perform when compared to a real-life situation. Furthermore, the small population where subjects were recruited presented a limitation. Coaches from North Dakota and Minnesota were recruited. Coaches in other areas of the country may have different rules and regulations regarding CPR/BLS certifications that lead to different levels of CPR self-efficacy. Finally, the small number of participants was a limitation to this study. The low number of participants within this study was not comprehensive and may not be generalizable to the entirety of North Dakota and Minnesota.

Despite the lack of research, the positive relationship between self-efficacy and CPR performance in coaches is limited to this study, which was the first to examine this specific population. While our results suggest coaches are confident in their ability to perform high-quality CPR in a controlled environment, further research incorporating more realistic CPR assessments is needed to understand the relationship between confidence and CPR performance. Once a relationship is better understood, educational standards can be revised and edited to address psychological considerations that could increase overall quality of CPR within coaches.

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## APPENDIX A. CPR SELF-EFFICACY QUESTIONNAIRE

Please respond to each prompt using the six-point scale listed below.

1: Strongly Disagree
2: Disagree
3: Somewhat Disagree
4: Somewhat Agree
5: Agree
6: Strongly Agree

**In an emergency situation, I am confident that I can always…**

- Perform CPR in accordance with the 2015 American Heart Association (AHA) guidelines __
- Perform chest compressions with an adequate rate (100-120 compressions/minute) __
- Perform chest compressions with an adequate depth (≥5 but ≤6 cm) __
- Allow the chest to fully recoil while performing compressions __
- Correctly position hands during CPR (Over lower half of the sternum) __
- Provide high-quality CPR consistently during a prolonged (approx. 5 minutes) resuscitation attempt __
- Alert emergency services following set protocol and initiate CPR without delay __
- Guarantee minimal interruptions in chest compressions during the resuscitation attempt __

## APPENDIX B. CPR DELIBERATE FEEDBACK QUESTIONNAIRE

Please respond to each prompt using the six-point scale listed below.

1: Strongly Disagree
2: Disagree
3: Somewhat Disagree
4: Somewhat Agree
5: Agree
6: Strongly Agree

**After having my overall CPR QCPR score explained to me…**

- I had the feeling that the feedback I received was a useful contribution to learning about my CPR performance
- I felt comfortable with the way I received feedback from the researcher __
- The strengths of my performance were clearly explained to me ____
- The weaknesses of my performance were clearly explained to me __
- My stress level was high during my first 5 minutes of compression only CPR __