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ASSESSMENT OF CHEST COMPRESSION QUALITY — A SYSTEMATIC REVIEW

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ABSTRACT

INTRODUCTION: High-quality chest compression (CC) is a crucial factor that determines the survival of cardiac arrest patients. Adequate quality should be featured by appropriate compression rate and depth, and full chest recoil after each compression. The ranges are strictly determined in Resuscitation Guidelines. All these parameters are interdependent. Currently, there is a need to find or develop a universal index that will enable the definition and determination of the overall quality of CCs.

MATERIAL AND METHODS: A systematic review of the MEDLINE, EMBASE, COCHRANE, and GOOGLE SCHOLAR databases was performed. The authors aimed to find papers in which the quality of CC was assessed. The extracted information included measurement of the CC quality in a direct and objective manner — by analysing the depth, rate, and recoil of CC, position of the hands, duty cycle, and indirectly by evaluating chest compression fraction (CCF). Papers describing the quality of CC based on a combination of various components of the CC quality were selected for analysis.

RESULTS: In total 1604 publications were obtained. Among them, 21 articles satisfied the search criteria. In most of the papers, it was suggested that compressions should have been considered as correct when they met simultaneously all quality criteria. Only three papers presented any mathematical formula that could have been used for further comparisons.

CONCLUSIONS: Although many proposals have been developed, no single, universal, and commonly accepted indicator of resuscitation quality has been so far designed and subsequently applied. Further work on this subject is warranted and strongly recommended.

KEY WORDS: cardiopulmonary resuscitation; quality of health care; quality improvement; systematic review

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INTRODUCTION

Cardiopulmonary resuscitation (CPR) is one of the survival determinants of patients after sudden cardiac arrest (SCA). In recent years, a number of researchers and medical rescuers have been involved in studies focused on increasing the effectiveness of CPR. The summary of their findings has led to the International Liaison Committee of Resuscitation (ILCOR) recommendations. They have been considered as the basis

for publishing guidelines of resuscitation. In their subsequent updates, more and more attention has been paid to high-quality chest compressions (CCs). It has been shown that immediate CCs are crucial for successful resuscitation, and if performed before the arrival of ambulance with a rescue team may even triple the chances of victims to survive SCA [1, 2].

There is no doubt that overall quality of CPR is determined by several factors. CPR of adequate

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quality should be featured by appropriate compression rate and depth, full chest recoil after each compression, correct position of the hands, and a low rate of interruptions. The first four have been specified in the valid European Resuscitation Council (ERC) guidelines. The last component of CPR quality can be directly reflected by the parameter called the chest compression fraction (CCF). Rate, depth, and chest recoil depend on rescuer experience and physical work. The value of each of these factors has already been proven. However, it has not been indicated that any of the above-mentioned parameters prevail over another. It was also recognised that although they affect blood flow through different mechanisms, they are of equal importance.

The first phase of indirect cardiac massage is one compression followed by a second one, and then decompression. The proper compression depends on the rate and depth. Its role is not only to squeeze the heart itself but also to raise the intrathoracic pressure and eject blood from the thorax. Artificial compression, even carried out properly, produces cardiac output lower than physiological one. Therefore, CC must be performed faster than normal heart rate. However, it has been shown that overly rapid compressions are often too shallow [3]. The decompression phase allows the blood to flow through the coronary arteries. This is essential for maintenance of the myocardial perfusion.

In recent years, there have been more and more papers reporting application of medical simulations as a valuable tool to study CC quality. Up to now, many different mannequins compatible with computers have been designed to measure and analyse particular CC quality parameters. Currently, there is no single universal recommended index that would enable the definition and determination of the overall quality of CCs. Such an index would make possible a reliable comparison of CCs performed by various studies and in different study conditions and simulation scenarios.

In this systematic review it was assessed whether previously published articles clearly defined chest compression quality index, based on a combination of various components of the CC quality.

MATERIAL AND METHODS

Protocol registration

To standardise the research, the PRISMA 2009 study protocol was used. It was intended to guide the development of protocols of systematic reviews and

meta-analyses evaluating therapeutic efficacy. The study protocol was approved by the Institutional Review Board of Poznan University of Medical Sciences (No. KB764/19).

Search criteria

A systematic review of the MEDLINE, EMBASE, COCHRANE, and GOOGLE SCHOLAR databases was performed. The original papers published before May 2019, in which the quality of CPR was stated as the main purpose, were included. Our analysis involved all studies on both humans and simulators. An additional source of publications was an overview of references of the scientific reports found in the aforementioned search engines.

Because the predominant aim of this study was to analyse the methods used to assess CC quality, the authors refrained from searching with the use of PICO (Population, Intervention, Comparison, Outcome) structure.

Data collection process

A two-stage process for screening and selection was applied. Initial screening was based upon checking the titles and abstracts of retrieved citations against predefined inclusion and exclusion criteria. Full texts of potentially relevant citations were reviewed, and studies that met eligibility criteria were retained. Two independent investigators performed the selection of articles. Disagreements between two investigators were resolved during meetings or adjudicated by a third reviewer. Any papers classified as 'unclear' after review of the full text were resolved by discussion. The process of study selection is outlined in Figure 1.

Eligibility criteria

Data were extracted only from full-text articles published in English. Extracted information included measurement of the CC quality in a direct and objective way — by analysing depth, rate and recoil of CC, position of the hands, and duty cycle, and indirectly by evaluating CCF.

Only papers describing the quality of CC using a coefficient that consisted of at least two of the above-mentioned parameters connected with a mathematical or propositional formula were chosen. The study excluded papers describing the physiological impact of CC on such parameters as blood pressure, end-tidal carbon dioxide, or cerebral perfusion pressure. The particular exclusion and inclusion criteria are summarised in Table 1.

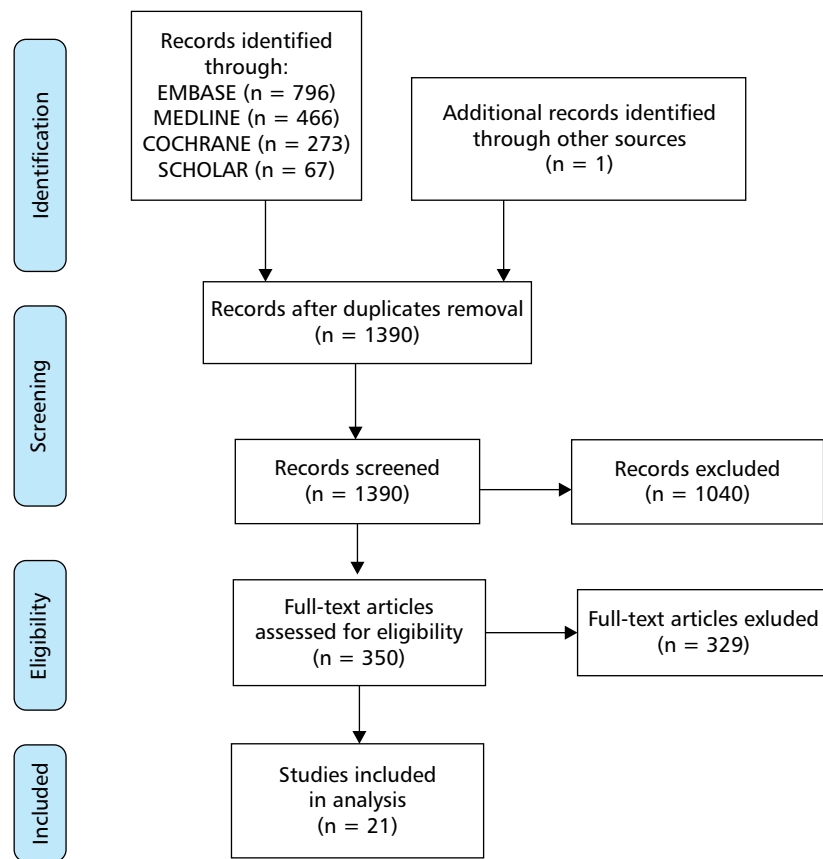


FIGURE 1. Research flowchart according to PRISMA statement

Inclusion criteria	Exclusion criteria
1. Published randomised, controlled clinical trials	1. Guidelines, meta-analysis, systematic reviews, literature reviews, editorials, commentaries, case reports/case series, conference abstracts, or proceedings
2. Human subjects or simulation trials	2. Non-clinical reports (e.g. animal models, in vitro or ex vivo experimental studies).
3. Assessment of quality of resuscitation	3. Studies focused on assessment of quality of resuscitation activities other than chest compressions (e.g. ventilation, compliance to guidelines)
4. Full, original articles	4. Studies focused on physiological effect of chest compression (e.g. blood pressure, cerebral or coronary perfusion pressure, end-tidal carbon dioxide)
	5. Resuscitation other than cardiopulmonary (e.g. fluid resuscitation in trauma victims)
	6. The results in which the quality of chest compression parameters was indicated but not related to each other
	7. Subjective method of quality assessment (e.g. provider's or instructor's perception),
	8. Articles not reporting original data
	9. Full text not available in English

RESULTS

As a result of the review of the four mentioned databases, 1603 publications were obtained. One additional paper was qualified after a search of the references of the aforementioned articles. In

the next step, repetitive publications were excluded, and 1390 papers were selected for abstract analysis. At this stage, after taking into consideration the exclusion criteria, 350 publications were qualified for full-text analysis. Among them, only 21 articles

satisfied search criteria, and a systematic review of their findings are presented in Table 2.

In 10 of the selected papers, it was proposed that CPR quality should be defined as the percentage of compressions that met simultaneously all

criteria defined by the authors (various criteria in different papers) [4–13].

Only three papers presented a mathematical formula that could have been used for further comparison and detailed analysis [13–15].

Table 2. Results of literature search

No.	Author (country, year)	Title	Formula
1	Abelairas-Gomez et al. (Spain, 2018)	Acute muscle fatigue and CPR quality assisted by visual feedback devices: a randomised crossover simulation trial	Dichotomous quality (yes or no) if > 70% of CC with corrR AND corrD AND corrC AND corrH
2	Abelsson et al. (Sweden, 2018)	Cardiopulmonary resuscitation quality during CPR practice versus during a simulated life-saving event	Compression score (part of Laerdal CPR score)
3	Anderson et al. (Canada, 2019)	Optimal training frequency for acquisition and retention of high-quality CPR skills: a randomised trial	Excellent CPR = % of CC with > 90% corrR AND > 90% corrD AND > 90% corrC
4	Baldi et al. (Italy, 2017)	Real-time visual feedback during training improves laypersons' CPR quality: a randomised controlled manikin study	Laerdal® CPR score
5	Braunecker et al. (Germany, 2015)	Comparison of different techniques for in microgravity — a simple mathematic estimation of CPR quality for space environment	Compression Product = R × D [mm/min]
6	Buleon et al. (France, 2016)	Impact of a feedback device on chest compression quality during extended manikin CPR: a randomised crossover study	Efficient CC = % of CC with corrR AND corrD AND corrRF
7	Cortegiani et al. (Italy, 2016)	Use of a real-time training software (Laerdal QCPR®) compared to instructor-based feedback for high-quality chest compressions acquisition in secondary school students: a randomised trial	Laerdal® CPR score
8	Fernando et al. (Canada, 2018)	Analysis of bystander CPR quality during out-of-hospital cardiac arrest using data derived from automated external defibrillators	Combined rate and depth = % of CC with corrR AND corrD
9	Fischer et al. (Austria 2011)	Quality of resuscitation: Flight attendants in an airplane simulator use a new mechanical resuscitation device: a randomised simulation study	Effective compression = % of CC with corrD AND corrC AND corrH
10	Fischer et al. (Austria, 2011)	Effects and limitations of an AED with audiovisual feedback for CPR: a randomised manikin study	Effective compression = % of CC with corrD AND corrC AND corrH
11	Furelos et al. (Spain, 2017)	Can surf-lifeguards perform a quality CPR sailing on a lifeboat? A quasi-experimental study	Quality of chest compressions = [(%corrR + %corrD + %corrC)/3]
12	Gonzalez-Salvado et al. (Spain, 2019)	A community intervention study on patients' resuscitation and defibrillation quality after embedded training in a cardiac rehabilitation programme	Laerdal® CPR score
13	Grief et al. (Austria 2013)	Effective compression ratio: a new measurement of the quality of thorax compression during CPR	Effective compression ratio = flow time [%] x effective compression [%] (%corrD AND %corrC AND %corrH)
14	Harve et al. (Finland, 2009)	Defibrillation and the quality of layperson CPR: dispatcher assistance or training	Quality = % of CC with corrD and corrH
15	Iskrzycki et al. (Poland, 2018)	The impact of the use of a CPRMeter monitor on quality of chest compressions: a prospective randomised trial, cross-simulation	Laerdal® CPR score
16	Lin et al. (Canada, 2018)	Improving CPR quality with distributed practice and real time feedback in paediatric healthcare providers: a randomised controlled trial	Excellent CPR = % of CC with > 90% corrR AND > 90% corrD AND > 90% corrC
17	López-González et al. (Spain, 2016)	Muscular fitness as a mediator of quality CPR	Adequate CC = % of CC with 100% corrR AND 100% corrD AND 100% corrC AND 100%corrH AND 100%corrCDR

Table 2. (Cont.) Results of literature search

No.	Author (country, year)	Title	Formula
18	Martin et al. (UK, 2013)	Does a more “physiological” infant manikin design effect chest compression quality and create a potential for thoracic over-compression during simulated infant CPR?	Overall CPR quality index = % of CC with corrR AND corrD AND corrRF AND corrCDC
19	Mortensen et al. (Denmark, 2010)	Comparison of the quality of chest compressions on a dressed versus an undressed manikin: a controlled, randomised, cross-over simulation study	Quality = % of CC with corrD AND corrC AND corrH
20	Smereka et al. (Poland, 2018)	The effect of chest compression frequency on the quality of resuscitation by lifeguards: a prospective randomised crossover multicenter simulation trial	Laerdal® CPR score
21	Sutton et al. (USA, 2015)	First quantitative analysis of cardiopulmonary resuscitation quality during in-hospital cardiac arrests of young children	Excellent CPR = % of CC with corrR AND corrD AND CCF > 80% AND leaning < 20%

AED — automated external defibrillator; CPR — cardiopulmonary resuscitation; CC — chest compressions; R — rate of compressions; D — depth of compressions; C — chest recoil; corrR — correct rate; corrD — correct depth; corrC — correct recoil; corrH — correct hands placement; corrRF — correct release force (< 2.5 kg); corrCDR — correct compression/decompression ratio (50%); corrCDC — correct compression duty cycle (50%).

In two publications the authors assumed that “CPR is excellent” when more than 90% of compressions fulfilled the criteria of optimal CC rate and depth as well as chest recoil [16, 17].

In one paper the authors defined good quality of CCs if 70% of them were perfect in terms of rate, depth, recoil, and position of the hands [18].

In six studies, the indicator developed by the Laerdal corporation was used for the analysis [19–24]. It is a part of the software for analysing resuscitation performed in simulation conditions. According to “Laerdal CPR scoring explained, Revised in 2015”, the quality of the CPR consists of subsections: compressions, ventilation, and the flow fraction. The quality of compressions themselves depended on: rate, depth, release, number of compressions per cycle, and position of the hands.

DISCUSSION

A systematic review regarding the quality of CPR is difficult due to the wide variety of variables, the research methods applied, and the heterogeneous groups of patients. Talikowska et al. also indicated the need for clear definitions that would facilitate the proper analysis of such data [25].

According to the American Heart Association (AHA) / ERC 2015 guidelines, CC is a very early and important element of effective CPR. High CC quality should be maintained throughout the whole resuscitation. The following components of high-quality CPR were defined: CC rate between 100 and 120 per minute, CC depth between 50 and 60 mm,

and full chest recoil after each compression [26]. To avoid fatigue and its negative impact on CPR efficiency, rescuers should change at least every two minutes. Their hands should be placed directly in the middle of the chest. Moreover, excessive ventilation should be avoided.

We are aware that maintaining high-quality CPR is difficult even for professional paramedics. There are many factors that can unfavourably affect the quality of CCs. Some of them, such as basal metabolic rate, mean fat-free mass, trunk muscle mass, and left and right arm muscle mass, are independent of the rescuers [27].

An additional important parameter is CCF. It is defined as the proportion of time of CCs during CPR [28]. It has been proven that survival to hospital discharge was the highest when CCF exceeded 60%. Adjusted odds ratio for 10% of linear change was 1.11 (1.01–1.21) [29]. Based on these results, AHA has adopted a CCF value of 60% as the minimum to maintain CPR quality. In addition, AHA indicates that, depending on the conditions, up to 80% of CCF can be achieved [30].

When CPR is provided by a single rescuer in the BLS algorithm (compressions, bag-valve-mask ventilation, automated defibrillation), the CCF is reduced largely by interruptions caused by automated external defibrillator analysis and ventilation. In advanced resuscitation teams, interruptions are performed mainly during analysis of heart rhythm and defibrillation. Good cooperation between rescuers and their awareness of the paramount significance of continuous compressions is the most important

factor. Other factors increasing CCF include technical elements such as the use of self-adhesive electrodes or early application of advanced airway support [31].

In the results of the meta-analysis published in 2017 the authors paid attention to contradictory available data on correlation between CCF and survival. They found two studies in which an increase in survival was presented (by mean CCF at 72%), whereas five others did not show any association (by mean CCF at 65%) [32]. Additionally, Wik et al. noted that higher CCF predicted longer survival only when the other resuscitation activities were well performed [33].

It can be assumed that all the above factors have equal importance. Therefore, it is not possible to indicate one critical parameter for the better patient's survival. Undoubtedly, the CCF should be the highest possible without any detriment of the quality of CC. The CCF indicates not the quality of the compressions but also the efficiency of the work and coordination of the whole team. The quality of the CC itself is most dependent on the ability and physical condition of the provider. This is the effect of the physical strength of the rescuer using the appropriate technique.

In none of the papers found in the review was a multiplier applied in the formula. It means that a single compression is treated in a dichotomous way: as correct or incorrect, regardless of how many quality parameters need to be improved. That approach is reasonable if one considers whether particular compression is correct in terms of the CPR guidelines. However, it does not give the possibility of a reliable comparison of the quality of compressions carried out in various circumstances. For example, Ahn et al. estimated that depending on the surface on which the mannequin was placed, the rate of compressions can be different, but their depth and relaxation are independent [34]. In this scenario, the use of any formula other than that proposed by Braunecker et al. may result in the conclusion that all compressions in the experimental test would be considered as incorrect. However, the authors assessed only two parameters of CCs, such as their rate and depth [15]. This may be not appropriate because the role of a rescuer is also to provide complete chest relaxation.

In 13 publications, one of the determinants of quality was the percentage of correct hand positioning defined in the valid guidelines. However, it is not possible to calculate it by any mathematical model due to the individual biological variability in body

construction. This is rather a subjective rescuer's determination of the "middle" or lower half of the sternum. To the best of our knowledge, there are no studies estimating the impact of hand displacement on the quality of treatment or patient survival, as in the case of the other parameters. In recent years, interesting findings of imaging studies have been presented. They have shown that the optimal compression point was found 3 cm left of the origo [35]. It has also been suggested that in obese individuals the appropriate place of compressions may be higher than was indicated previously [36]. Summarising, the compression quality formula should not include this parameter. However, it must be (like the CCF) discussed separately.

CONCLUSIONS

Our scientific search enabled us to conclude that so far, no single, universal indicator of resuscitation quality has been designed and subsequently applied, although many proposals have been developed. Each of the indicators of resuscitation quality discussed in this paper is of interest but also has some disadvantages. Bearing in mind the importance of optimal quality of CRP, further intensive and extensive studies of this issue are warranted and strongly recommended.

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