Impact of personal protective equipment on the effectiveness of chest compression - A systematic review and meta-analysis

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ABSTRACT

Background and objectives: To assess the impact of personal protective equipment (PPE) on different aspects of chest compression (CC) during cardiopulmonary resuscitation, we conducted this study.
Methods: This systematic review was performed according to the PRISMA. We searched PubMed, EMBASE and Web of Science from inception to June-6, 2020, limiting to the studies that reported the comparison of the effectiveness of CC in terms of CC rate, CC depth, the proportion of adequate CC rate, the proportion of adequate CC depth or proportion of adequate recoil; in study arms with or without PPE. Risk of bias was assessed by the ROB-2 and ROBINS-I tool. Quantitative data synthesis was done using the generic inverse variance method and the fixed-effects model.
Results: Five simulation-based studies were finally included. A Significant decrease in CC rate (SMD: -0.28, 95%CI: −0.47 to −0.10) and CC depth (SMD: -0.26, 95%CI: −0.44 to −0.07) were observed in the PPE arm as compared to the no-PPE arm. The difference in CC rate was more prominently seen in adult CPR than in paediatric CPR. Without PPE, the proportion of adequate CC rate delivered was 0.74, which reduced significantly to 0.60 after use of PPE ($p - 0.035$). Similarly, the proportion of adequate CC depth was significantly lesser ($p - 0.001$) in PPE arm (0.55), as compared to that of the no-PPE arm (0.78).
Conclusion: The use of PPE compromises the quality of CC during CPR significantly, and newer ways to deliver chest compression has to be investigated.
This study was prospectively registered in PROSPERO (CRD42020192031).

1. Introduction

The outbreak of novel coronavirus disease 2019 (COVID-19) started in Wuhan, Hubei Province, China, in late December 2019. The resulting pandemic has infected almost 7 million people globally with nearly 400,000 deaths, as of May, 2020 [1]. According to current evidence, COVID-19 virus is primarily transmitted between people through respiratory droplets and contact routes [2,3].

Aerosol transmission is possible in procedures that lead to the generation of aerosol, which include endotracheal intubation, open suctioning, bronchoscopy, administration of nebulised medications, non-invasive positive pressure ventilation and cardiopulmonary resuscitation (CPR).[4] Health care workers (HCW) are particularly at risk of contracting the infection, and they are exposed to these aerosols while performing such procedures. [5] CPR is a standard emergency room

procedure leading to high aerosol generation and is associated with the risk of transmission of infection to health care workers. [6] The European Resuscitation Council (ERC), the American Heart Association (AHA) and the Australasian College for Emergency Medicine recommend the use of personal protective equipment (PPE) by the HCW involved in resuscitating cardiac arrest patients [6,7,8]. Few studies have demonstrated that the performance level of HCW during life-saving procedures like CPR, intravenous cannulation and endotracheal intubation decreases while wearing PPE. [9,10,11]

High-quality CPR is the backbone of the management of a cardiac arrest and AHA has given the particular emphasis on the rate of chest compressions (CC), depth of CC and minimising the interruptions between CC in defining a high-quality CPR.[12] This systematic review and meta-analysis aimed to investigate the impact of PPE on different chest compression (CC) parameters during CPR. The primary objective was to summarise the changes in mean CC rate and CC depth, in study arms (no-PPE arm versus PPE arm). The secondary objectives were to summarise the proportion of adequate CC rate and depth provided

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and compare this in both the study arms. This study was prospectively registered in PROSPERO (CRD42020192031) [13].

2. Materials and methods

2.1. Data sources and searches

This systematic review was performed according to the Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA guidelines).[14] Databases including PubMed, EMBASE and Web of Science were searched from inception to June-6, 2020. Two independent investigators (AK, RM) searched the databases using search terms like 'chest compression', 'cardiopulmonary resuscitation', 'CPR', 'personal protective equipment', 'PPE' and 'N95 mask' (search query available in Supplementary Table – S1. There were no restrictions in terms of country, publication language or publication date. Reference lists of all relevant articles and 'related citation' search tool of PubMed was checked for any additional publications.

2.2. Selection Criteria

Study selection was performed by two independent investigators (AK, SS). We included studies that reported the data on the comparison of the effectiveness of CC in terms of either CC rate, CC depth, the proportion of adequate CC rate, proportion of adequate CC depth or proportion of adequate recoil; in study arms with (PPE group) or without PPE (no-PPE group). Case reports, duplicate publications and reviews were excluded. Discrepancies between reviewers were resolved in the presence of a third reviewer (RM).

2.3. Data abstraction and quality assessment

Data collected included study characteristics such as authors, publication date, study design, information about both study arms (PPE versus no-PPE group) like sample size, type of PPE used and different CC parameters. The CC parameters collected were mean CC rate (per minute), mean CC depth (in millimetres), the proportion of adequate CC rate provided, the proportion of adequate CC depth provided, proportion of time adequate chest recoil was allowed and duration of CC provided along with the definitions used for appropriate CC rate and depth. The proportion of the parameters mentioned above was defined as the ratio of the duration of correct CC (rate, depth or recoil) to the total duration for which CC was provided. Qualitative assessment of rescuer's fatigue was also extracted from the included studies.

One reviewer (AK) extracted the data, and the second reviewer verified the data independently (SS). The methodological quality of the randomised trials was assessed by Cochrane's ROB-2 (Risk of Bias – 2) tool [15], and that of non-randomised studies was determined by Cochrane's ROBINS-I (Risk of Bias in Non-randomised Studies of Interventions) tool [16]. Two authors (JN, SS) performed the quality assessment separately, and disagreements were resolved by consensus in the presence of a third reviewer (AK).

2.4. Quantitative data synthesis

The change (no-PPE versus PPE group) in the continuous variables like mean CC rate and mean CC depth were summarised in terms of standardised mean difference (SMD) by Cohen's method using generic inverse variance method[17]. The proportion of adequate CC rate, CC depth and CC recoil were pooled separately in both the arms (no-PPE versus PPE group) and were compared using Chi-square statistics (p-value < 0.05 was considered statistically significant), as described by Campbell [18] and Richardson et al. [19]. Fixed effects pooling was used for meta-analysis. To assess the heterogeneity among studies, inconsistency statistics (I2) were calculated. Significant heterogeneity was considered to be present when I2 was greater than 50% [20].

Publication bias was assessed visually by constructing funnel plots and calculating Egger's regression equation. The p-value for Egger's regression coefficient less than 0.10 was considered as significant publication bias [21]. Subgroup analysis, according to the type of manikin used was undertaken. All data were collected in Microsoft Excel Spreadsheet (Office 365). Fixed-effects analysis, generation of forest plot, assessment of heterogeneity and publication bias were performed with the METAN, METAPROP and METAFUNNEL platform for STATA (version-14.2); StataCorp, College Station, TX). Ethical approval was not needed, as this study was a systematic review.

3. Results

3.1. Search results and study characteristics

The literature search flow diagram is summarised in PRISMA format (Fig. 1) and detailed PRISMA checklist is available in Supplementary Table – S2. Using our search criteria, we identified 109 studies, of which forty-eight were from PubMed, fifty-two were from EMBASE, four were from Web of Science, and five were from hand-searching of references and citations of the selected articles. A total of 22 records were screened after removal of duplicates. A total of 11 full-text articles were assessed for eligibility, and six articles were excluded due to various reasons, as shown in Fig. 1. Finally, five studies were included in this meta-analysis.

3.2. Characteristics of the included studies

A total of five studies, consisting of 456 observations (228 in each of no-PPE and PPE arms), were selected for this meta-analysis (Table 1 and Supplementary Table – S3). Studies were published between January 2015 to May 2020. All the studies were simulation-based, of which four were conducted in adult manikins [10,22,23,24] and one in paediatric manikin [11]. Two studies were of 'before and after PPE' design [11,22], two of 'crossover randomised' design [10,23] and one was of 'parallel randomised' design [24]. CC providers were physicians, nurses and emergency medical technicians. During CPR, providers used Level-C PPE (gloves, gown, respirator with filter, boots according to Occupational Safety and Health Administration guidelines) in three studies [10,22,23], Level-B/C PPE in one study [11] and only N95 face mask in one study [24]. Practical assessment of different parameters was done for 2 min in two studies [10,24] and 4 min in two studies [22,23]. As Donoghue et al. had provided CC data from 0.5 min to 5 min duration, only CC parameters recorded at 2 min were included for this meta-analysis [11]. All five studies had provided information on the mean rate and depth of CC. In contrast, only 3 out of 5 studies (Supplementary Table – S3) had provided information on the proportion of adequate CC rate and adequate CC depth [10,23,24], and only Tian et al. had provided data on CC recoil [11]. Adequate CC rate was defined as the rate of 100 to 120/min in all studies except in the study by Shin et al., where a minimum rate of 100/min was considered adequate. Adequate CC depth was defined as the depth of minimum 50 mm in all the included studies.

Results of the quality assessment of the included studies are summarised in Table 1, and the detailed risk of bias analysis is available in Supplementary Figure – S1 (ROB-2 infographics) and Figure – S2 (ROBINS-I infographics). Among the randomised trials, studies by Chen et al. [10] and Tian et al. [24] were of low risk of bias, whereas Kim et al. [23] were of a high risk of bias due to unavailability of information about randomisation process. Donoghue et al. had a serious risk of bias (due to lack of adjustment for confounders like a variation in participant designation and training) [11]. ROB could not be assessed for Shin et al. due to unavailability of information in multiple domains of ROBINS-I tool.
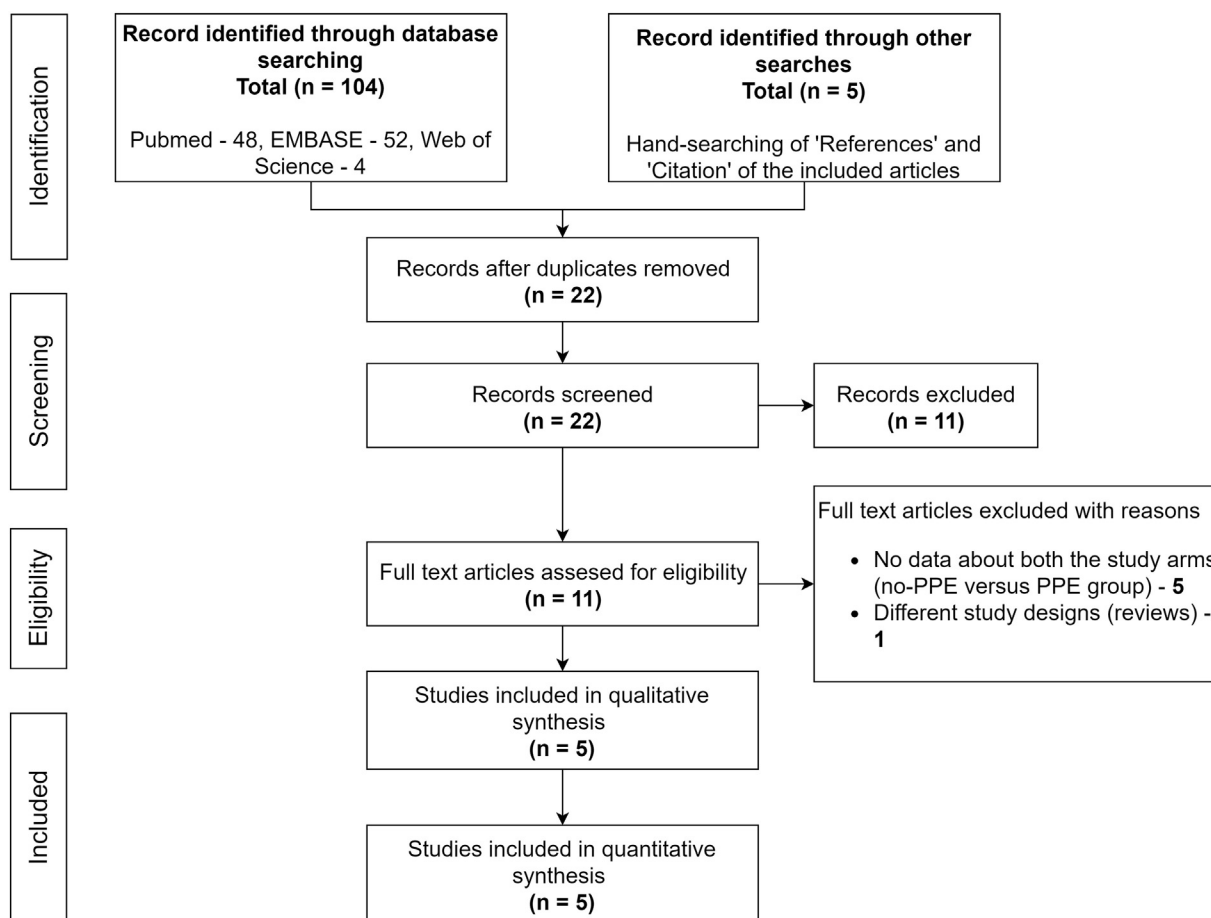
Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram.

3.3. Quantitative data synthesis results

A Significant decrease in CC rate was observed in the PPE arm as compared to no-PPE arm (SMD: -0.28, 95%CI: −0.47 to −0.10) (Fig. 2). Similarly, with the use of PPE, there was a significant reduction in CC depth also (SMD: -0.26, 95%CI: −0.44 to −0.07) (Fig. 3). Significant statistical heterogeneity was observed in the meta-analysis of studies for CC rate (I2: 76.5%) and CC depth (I2: 77.2%). To investigate the

cause of heterogeneity, subgroup analysis according to the type of manikin used was undertaken. It was found that during adult CPR, there was a significantly higher reduction in CC rate after use of PPE (SMD: -0.65, 95%CI: −0.39 to −0.91, I2: 0%), as compared to that during paediatric CPR (SMD: 0.10, 95%CI: −0.17 to 0.36, I2: not applicable, as only one study was included). For CC depth, statistical heterogeneity among the included studies, reduced from overall I2 of 77.2% to I2 of 71.8% for the subgroup of adult manikin's studies.

Table 1
Characteristics of the included studies in the systematic review and meta-analysis

Study ID	Study design	Manikin used	Participants	PPE used	Time duration	Sample size		Chest compression rate per minute (mean ± SD)		Chest compression depth in mm (mean ± SD)		Risk assessment
						'no-PPE' arm	'PPE' arm	'no-PPE' arm	'PPE' arm	'no-PPE' arm	'PPE' arm	
Shin 2015	Before and after PPE, simulation	Adult	EMT	Level - C	4 min	20	20	117.8 ± 14.2	111.9 + 14	50.2 + 6.1	50.5 + 6	No information
Chen 2016	Randomised crossover, simulation	Adult	Physicians	Level - C	2 min	40	40	105.4 + 8.3	98.1 + 8.9	49.3 + 6.9	42.5 + 6.8	Low
Kim 2016	Randomised crossover, simulation	Adult	EMT	Level - C	4 min	20	20	117.8 + 13.8	112.2 + 13.4	50.2 + 6.1	50.5 + 5.9	High
Donoghue 2020	Before and after PPE, simulation	Paediatric	Physicians, nurses and EMT	Level - B and C	2 min	108	108	108.1 + 18.1	109.7 + 15.1	58.4 + 15.2	58.4 + 12.7	Serious
Tian 2020	Randomised, simulation	Adult	Physicians and nurses	N95 mask	2 min	40	40	118 + 16	107 + 16	52 + 7	47 + 9	Low

Footnotes: PPE – personal protective equipment, Level – B and C PPE according to Occupational Safety and Health Administration guidelines, EMT – emergency medicine technicians, 'PPE' arm – study arm with PPE, 'no-PPE' arm - study arm without PPE, SD – standard deviation, ^ Risk of Bias analysis for non-randomised studies using ROBINS-I tool (Risk Of Bias In Non-randomised Studies of Interventions), * Risk of Bias analysis for randomised trials using Cochrane ROB-2 tool.
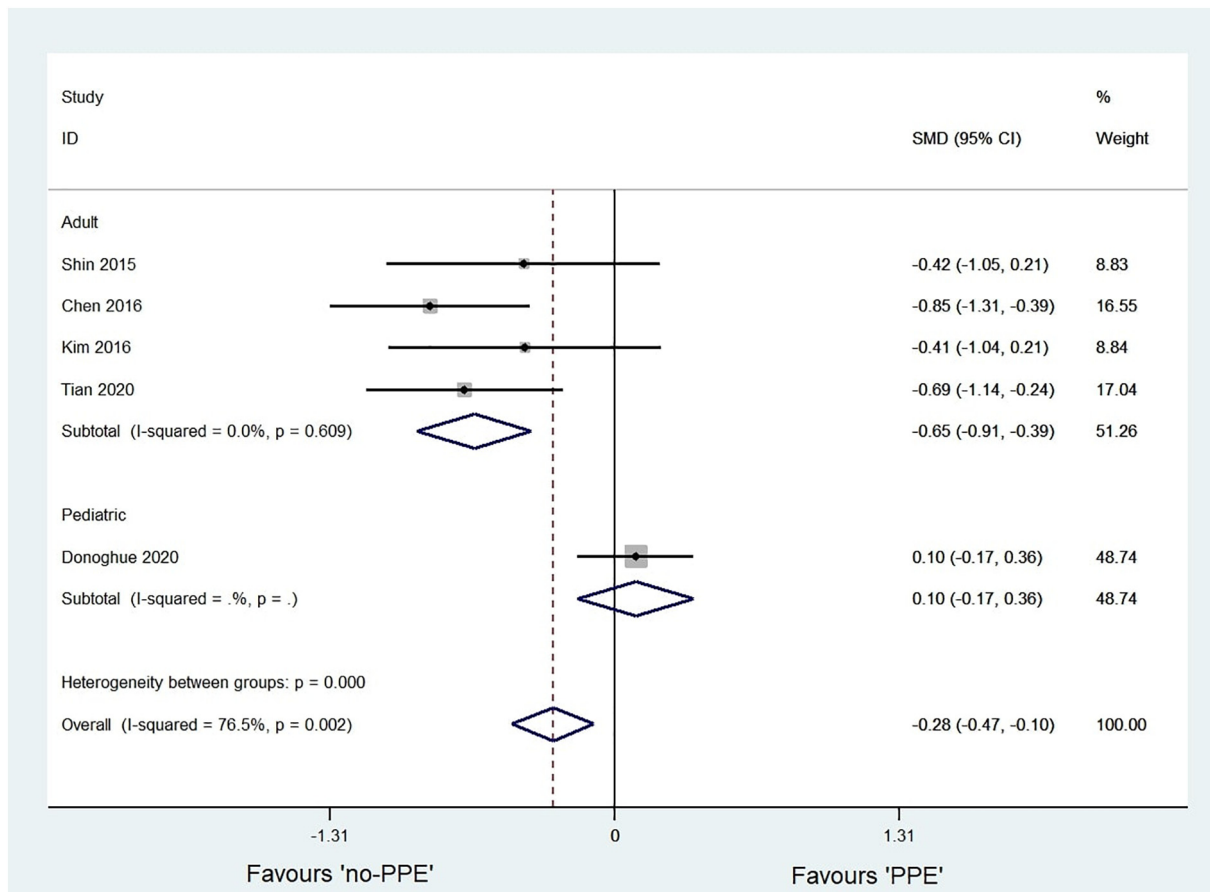
Fig. 2. Forest plot summarising the standardised mean difference (SMD) of chest compression rate (per minute). Footnotes 'PPE' – study arm with personal protective equipment, 'no-PPE' - study arm without personal protective equipment, I2 – heterogeneity statistics.

To have a better clinical understanding of the effect of PPE use on CC parameters, the overall proportion of adequate CC rate and depth were calculated and compared in both arms. Without PPE, the proportion of adequate CC rate was 0.74 (95%CI: 0.69–0.79), which reduced significantly to 0.60 (95%CI: 0.54–0.65) after use of PPE (chi-square *p-value:* 0.035) (Fig. 4). Similarly, the proportion of adequate CC depth was significantly less (chi-square *p-value* < 0.001) in PPE arm (0.55, 95%CI: 0.50–0.61), as compared to that of no-PPE arm (0.78, 95%CI: 0.73–0.82) (Fig. 5). Only Tian et al. had provided data on the proportion of adequate recoil, hence meta-analysis could not be done (0.98 in the no-PPE arm versus 0.91 in PPE arm).

There was no publication bias observed among the included studies (Egger's regression coefficients for meta-analysis of CC rate and CC depth were 0.166 and 0.646, respectively depicted in Supplementary Figure – S1 and S2).

4. Discussion

Our systematic review and meta-analysis showed that the use of PPE affects the quality of CPR as there was a significant reduction in rate and depth of chest compressions while using PPE as compared to the no PPE arm. It was also found that the decrease in chest compression rate and depth was significantly higher after the use of PPE in adults as compared to the paediatric CPR.

ERC and AHA guidelines on the management of cardiac arrest give equal emphasis on the rate and depth of chest compressions in determining the survival and outcome of cardiac arrest [12]. Chen et al. in their randomised cross over simulation study done demonstrated a significant reduction in the percentage of effective chest compressions

delivered while wearing PPE [10]. It was shown that high quality of chest compression is associated with a degree of work comparable to high-intensity aerobic exercise. Rescuers develop fatigue during CPR, and fatigue leads to deterioration of quality of chest compression. Chen et al. had also shown that the increase in heart rate, mean arterial pressure and subjective fatigue score values were significant with the use of PPE (*p* < 0.001) [10]. The study by Kim et al. had shown an increase in interruption in chest compressions while wearing PPE and has attributed it to the difficulty in changing body postures and securing the airway for proper positive pressure ventilation [23]. Another simulation trial by Malysz et al. has also shown that use of PPE causes a significant reduction in chest compression quality and hence has recommended the use of automated chest compression devices or reducing the duration of CPR cycle to 1 min [25]. Since most of these studies were carried out in manikins/simulated environment, none of the study could include the psychological factors which may hinder the delivery of high quality chest compressions while wearing PPE like the fear of breach in PPE and the associated risk of acquiring infection while performing resuscitation.

Out of all studies included only the one conducted by Donoghue et al. was done on the paediatric manikin [11]. Donoghue et al. had found no significant difference in chest compression parameters between the PPE and no PPE arm. There was also no difference in fatigue of rescuers at 2 min in both arms [11]. This may be because of the lesser amount of physical activity required in paediatric chest compression as compared to adult chest compression.

As CPR is an aerosol-generating procedure, and there are risks of acquiring COVID 19 infection during resuscitation, HCW involved in such procedures must be wearing PPE [7]. This at the same time carries the
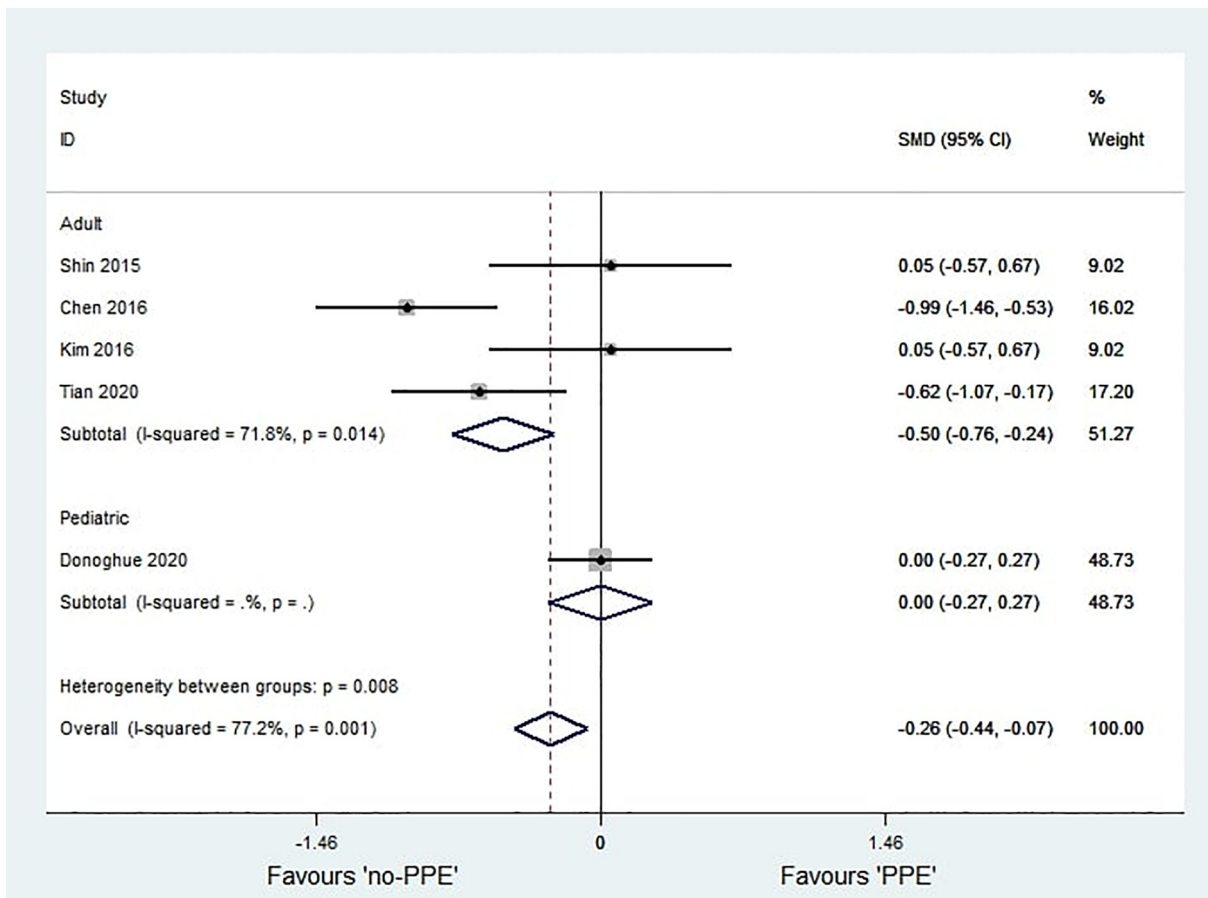
Fig. 3. Forest plot summarising the standardised mean difference (SMD) of chest compression depth (in millimetres). Footnotes 'PPE' – study arm with personal protective equipment, 'no-PPE' - study arm without personal protective equipment, I2 – heterogeneity statistics.

concern of delivery of inadequate chest compression (in terms of both rate and depth of chest compressions) and easy fatigability of rescuers while wearing PPE, which will affect the outcome of cardiac arrest adversely [10,11,22-25]. Though AHA recommends minimum interruption while doing compression, in a scenario where the operator has to wear a level-C PPE, can frequent switching with a shorter-cycles of one minute or 90 s improve quality of CPR has to be studied [6,7].

Another solution is to increase the number of chest compressors in a CPR team and hence to give enough rest in between compression. But this, in turn, is possible only at the cost of more HCW being exposed to the aerosol. Giving quality resuscitation in the time of infectious disease pandemic is a unique challenge. With the fear of contracting the infection and reduced work efficiency associated with wearing a level-C PPE, there is a need to improvise and devise ways so that the quality
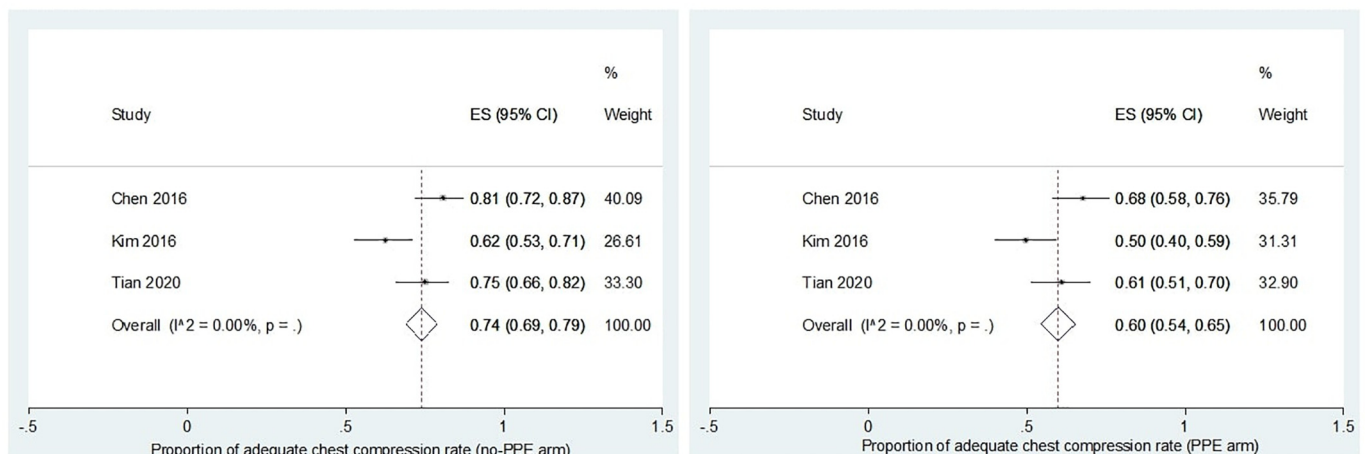

Fig. 4. Figure showing a significant reduction of the proportion of 'Adequate chest compression rate' provided in 'no-PPE' versus 'PPE' arms (chi-square *p-value*: 0.035). Footnotes: 'PPE' – study arm with personal protective equipment, 'no-PPE' - study arm without personal protective equipment, I2 – heterogeneity statistics.
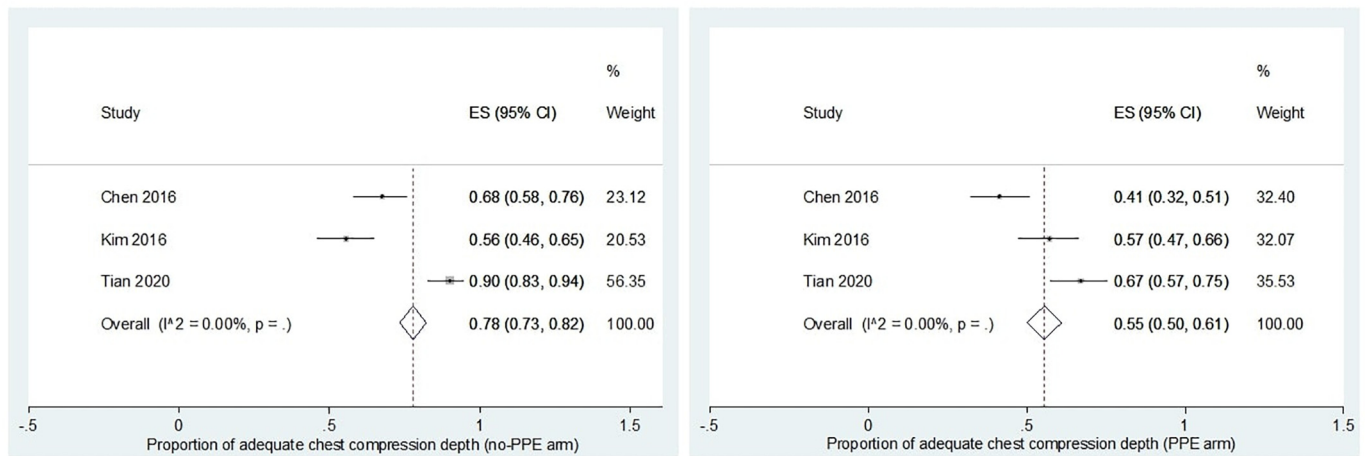
Fig. 5. Figure showing a significant reduction of the proportion of 'Adequate chest compression depth' provided in 'no-PPE' versus 'PPE' arms (chi-square *p-value* < 0.001).

of care is not compromised to our patients. This may include a more breathable PPE gown, a separate resuscitation team who are on a shorter shift, and a shift to mechanical CPR devices wherever feasible. Further studies, both simulations based and real-time resuscitation has to be done in this regard.

5. Limitations

There were several limitations to our study. Only simulation-based studies were included in this meta-analysis. None of these studies were conducted in real-life scenarios and during this COVID-19 pandemic (except Tian et al.) Out of the five studies included, only three studies had provided information on the proportion of adequate CC rate and depth, and only one study has provided information on CC recoil. Significant statistical heterogeneity was observed among the included studies for CC depth. Utilization of simulation based studies, the limited number of studies included and the sample size in these studies pose a challenge to our findings to be applied in real clinical scenarios. Finally, it is possible that new studies were published between the completion of the literature review and when this article was completed. However, we are not aware of any new publication since that time.

6. Conclusion

Use of personal protective equipment compromises with the quality of chest compression during CPR. As COVID-19 pandemic is expected to stay for a long time, further research needs to be done to find ways to improve CPR without compromising on the safety of the healthcare worker.

Credit(Authors' contribution)

The conceptualisation of the study: PA, AK, RM.
Data curation.
Article searching and study selection: AK, RM, SS
Data extraction: AK, SS
Formal analysis and software:
Quality assessment of the studies: AK, SS, JN
Data analysis: AK, JN
Manuscript writing: AK, RM, SS.
Overall conduct of the study: AK, PA.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2020.09.058.

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