Evaluating the Effect of a Pre-Arrival CPR Checklist on Resuscitation Quality During a Simulated Cardiac Arrest

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ABSTRACT

Introduction: While high-quality CPR is a cornerstone of cardiac arrest management, studies show variability in adherence to resuscitation guidelines. We sought to evaluate the effect of a CPR checklist on adherence to resuscitation guidelines during a simulated cardiac arrest scenario.

Methods: We conducted a double-blind randomized controlled trial involving Canadian emergency medicine residents. The intervention group was presented with a CPR checklist during the pre-brief and scenario, whereas the control group was not. The simulation scenario consisted of an adult patient arresting shortly after arrival to the emergency department, following which actor-provided ventilations and chest compressions deteriorated in a standardized fashion. We measured correction of deteriorating CPR quality and report the proportion of time during which high-quality CPR elements were provided.

Results: Thirty-five of 53 residents completed the study before COVID-19 closure. No difference in total arrest time with no or low-quality chest compressions was observed in the intervention group [median = 0.29 (interquartile range (IQR) 0.23-0.36)] vs. control [median = 0.42 (IQR 0.31-0.49)] p = 0.07. A significantly lower proportion of poor-quality chest compressions was observed in the intervention group [median = 0.24 (IQR 0.20-0.38)] vs. control [median = 0.42 (IQR 0.33-0.61)] p = 0.03. Furthermore, a significantly lower proportion of time with unacceptably high bag-mask ventilation rates were observed in the intervention group [median = 0.81 (IQR 0.61-1.00)] vs. control [median = 1.00 (IQR 1.00-1.00)] p = 0.02.

Conclusions: Our CPR checklist improved adherence to resuscitation guidelines amongst resident physicians in a simulated scenario.

RÉSUMÉ

Introduction : Bien qu'une RCP de haute qualité soit la pierre angulaire de la prise en charge de l'arrêt cardiaque, des études montrent que l'adhérence des directives de réanimation varie. Nous avons cherché à évaluer l'effet d'une liste de contrôle pour la RCP sur l'adhérence des directives de réanimation lors d'un scénario simulé d'arrêt cardiaque.

Méthodes : Nous avons mené un essai contrôlé randomisé en double aveugle auprès de résidents en médecine d'urgence canadiens. Le groupe d'intervention a été présenté avec une liste de contrôle pour la RCP lors de la séance d'information préalable et du scénario, contrairement au groupe témoin. Le scénario de simulation consistait en l'arrêt cardiaque d'un patient adulte peu après son arrivée aux urgences, à la suite duquel les ventilations et les compressions thoraciques effectuées par un acteur se détérioraient de manière standardisée. Nous avons mesuré la correction de la détérioration de la qualité de la RCP et rapporté la proportion de temps pendant laquelle des éléments de RCP de haute qualité ont été fournis.

Résultats : Trente-cinq des 53 résidents ont terminé l'étude avant la fermeture due à la COVID-19. Aucune différence dans la durée totale de l'arrêt cardiaque sans compressions thoraciques ou avec des compressions thoraciques de mauvaise qualité n'a été observée entre le groupe d'intervention [médiane = 0,29 (intervalle interquartile (IQR) 0,23-0,36)] et le groupe témoin [médiane = 0,42 (IQR 0,31-0,49)] (p = 0,07). Une proportion significativement plus faible de compressions thoraciques de mauvaise qualité a été observée dans le groupe d'intervention [médiane = 0,24 (IQR 0,20-0,38)] par rapport au groupe témoin [médiane = 0,42 (IQR 0,33-0,61)] p = 0,03. En outre, une proportion significativement plus faible de temps avec des taux de ventilation au masque et au ballon inacceptablement élevés a été observée dans le groupe d'intervention [médiane = 0,81 (IQR 0,61-1,00)] par rapport au groupe témoin [médiane = 1,00 (IQR 1,00-1,00)] p = 0,02.

Conclusions : Notre liste de contrôle pour la RCP a amélioré l'adhérence des directives de réanimation par les médecins résidents dans un scénario simulé.

INTRODUCTION

Cardiopulmonary resuscitation (CPR) and defibrillation represent the pillars of cardiac arrest management. Early effective CPR has been identified as the single most important intervention for patient survival following cardiac arrest (1,2). Resuscitation guidelines highlight five components of high-quality CPR, all of which are associated with improved survival to hospital discharge: 1) 100-120 compressions/minute; 2) minimal interruptions (chest compression fraction >80%); 3) compression depth > 5 cm in adults; 4) full chest recoil without leaning; and 5) ventilation rate <12 breaths/minute (1,3–8). These components of high-quality CPR have also recently been shown to increase survival to hospital discharge and neurologically intact survival when resuscitation efforts last for longer than 10 minutes (9).

The foundational knowledge and skillset involved in managing a cardiac arrest is primarily taught to physicians through basic life support (BLS) and advanced cardiac life support (ACLS) programs, with supplementation during residency training. Residents comprise a large component of the healthcare workforce and are routinely involved in cardiac arrest management during training. While BLS and ACLS programs provide trainees with a foundational basis for managing cardiac arrests, these brief courses alone cannot be expected to teach mastery of the critical ability to recognize and correct poor quality CPR. Literature has frequently reported sub-optimal quality of administered CPR and high variability in survival rates (1,9–11). A key pedagogical technique used to help residents acquire resuscitation and leadership skills is high-fidelity simulation. The literature on simulation for medical education has demonstrated improvements in trainee confidence, teamwork skills, and performance (12–18). Simulation has also been used to evaluate interventions aimed at improving CPR quality among medical trainees (12–18). Checklists have been implemented in healthcare as tools to facilitate a structured approach to critical problems, such as an operation or airway management, but have not yet been popularized as adjuncts to ensure CPR quality (19–23).

We sought to use simulation as an investigational method to evaluate the impact of a CPR checklist on resuscitation quality when used by emergency medicine (EM) residents in a cardiac arrest scenario. Our primary objective was the measurement of proportion of total arrest time without high-quality chest compressions. As secondary objectives, we measured: number of CPR cycles in which inadequate compressions were identified, proportion of time with inadequate chest compressions, total no compression time, number of pulse checks >10 seconds, and the proportion of time with a bag-mask ventilation (BMV) rate >12 breaths/min.

METHODS

Study Design

A randomized controlled trial comparing adherence to resuscitation guideline-recommended CPR performance between an intervention group using a pre-arrival CPR quality checklist and a control group without a checklist was conducted. Randomization was 1:1 and conducted in blocks of ten, stratified by year of residency training. Each study participant ran a single simulation scenario, with the rest of their team made up of trained study actors. The randomization sequence was generated using the Sealed Envelope Ltd. (2019) software (24). Participant assignment was concealed in equally weighted sealed opaque envelopes. Participants were blinded to both the intervention and study outcomes, while the data collector was blinded to group allocation.

Setting

The study was conducted between July 2019 and March 2020 at The University of Ottawa Skills and Simulation Centre (uOSSC), located in Ottawa, ON, Canada. Consent process, sharing of study forms, and initial scenario description (**Supplement 1**) occurred in a conference room. The session occurred in one of three identical high-fidelity simulation rooms.

Each simulation room was equipped with video recording technology, a high-fidelity computerized simulation mannequin (Laerdal 3G Plus), cardiac monitors, an emergency airway cart, and cardiac arrest 'crash' cart. The contents of these carts were standardized and prepared before each simulation case. Video recording technology and the display on all in-room monitors was operated by an experienced simulation technician in a control room. The simulation rooms were familiar to the residents and equipment/layout was similar to the emergency department where the residents practiced.

The cardiac arrest cart was equipped with an R-series Zoll defibrillation monitor with CPR feedback functions turned off. In addition, teaching mode was activated on the Zoll Monitor, allowing the control room technician to regulate

the rhythm displayed on both the overhead, in-room cardiac monitor, and the Zoll device.

Study Population

Participants were eligible for inclusion in the study if they were post-graduate year (PGY) 1-5 Royal College of Physician and Surgeons of Canada EM Residents, or PGY3 College of Family Physicians EM Residents enrolled at the University of Ottawa. All participants provided informed consent. We received ethics approval for this study from the Ottawa Health Science Network Research Ethics Board.

Study Intervention

The intervention consisted of a high-quality CPR checklist, outlining key parameters to high-quality CPR including reminders on minimizing interruptions, fast compressions (100-120/min), compression depth >5cm, full recoil without leaning, and ventilating <12 breaths/min (Supplement 2). The content of this checklist was based on resuscitation guidelines, and designed for simplicity based on investigator consensus (2,8).

After obtaining consent, a study staff not involved with data collection provided all participants with case scenario information (**Supplement 2**); the scenario was developed using a standardized simulation scenario development protocol (25). Participants from the intervention group were provided access to the CPR quality checklist, whereas participants from the control group were not. A standardized script was used to outline the scenario and deliver the intervention. Participants from both groups were given 2 minutes to prepare their team and delegate tasks as they felt appropriate, prior to entering the simulation room for case start. Study participants acted as case leader. Study participants had access to the handheld checklist during the resuscitation. They also had access to any tools they typically would use in their clinical practice (e.g. smart phone apps, ACLS cards etc). Case proceedings are detailed in **Supplement 3**.

This case protocol was practiced *a priori* over a 3-hour study implementation training session and implemented in a standardized fashion, with instructions being communicated to simulation team members at set time points during the case.

Following case completion, participants completed an exit survey (**Supplement 4** and **5**). The survey was developed by investigator consensus to assess quality of blinding, and reactions to the study design and intervention in accordance with Kirkpatrick's Evaluation Model (26). Residents received focused de-briefing and feedback according to the PEARLS framework for their education after study completion (27).

Methods of measurement

The following baseline characteristics were measured using a participant enrollment form (**Supplement 6**): age, sex, PGY of residency training, and previous number of years of experience as a nurse, paramedic or ACLS instructor if any.

Resuscitation quality was audited using audio/video recording and Software (LLEAP – Laerdal Learning Application v 7.2.0) which provides live, time-stamped compression rate, depth, and ventilation rate outputs applied to the simulation mannequin (SimMan 3G, Laerdal). Data was extracted by a trained investigator using a piloted data collection form. Study personnel involved in electronic data entry were blinded to participant group allocation.

Outcome measures

The primary outcome was the proportion of total time (seconds) elapsed without high-quality chest compressions, starting at the time of patient simulated cardiac arrest. High-quality chest compressions were defined as those which maintained: 1) 100-120 compressions per minute; 2) compression depth > 5cm; 3) full chest recoil without leaning. The absence of high-quality compressions was thus a composite of no compression and inadequate chest compression time.

The following were measured as secondary outcomes: 1) proportion of total time (seconds) elapsed with inadequate chest compressions (inadequate chest compressions were defined as chest compressions violating at least one of the three criteria above); 2) number of CPR cycles in which inadequate compressions were recognized (one CPR cycle was defined as the sequence of compressions-pulse/rhythm check-defibrillation-resumption of compressions); 3) total time (seconds) elapsed with no compressions when they should be provided; 4) proportion of pulse checks >10 seconds; 5) proportion of time (seconds) elapsed with BMV >12 breaths/min, following a pre-determined time point. Recognition of inadequate CPR was achieved if the study participant verbalized concerns about CPR quality or

provided instructions to correct it.

Data Analysis

Study participants were analyzed by allocated group assignment. Descriptive statistics are presented for demographics and exit survey data using frequencies with percentages or medians with interquartile ranges (IQR), as appropriate. Mann Whitney U testing was used to compare groups and calculate odds ratios (OR) with 95% Confidence Intervals (CI). All analyses were performed using Statistical Analysis System software (Version 9.4, Cari, NC, U.S.A).

Sample size

There was a total available sample size of 53 study participants undergoing EM training at our centre (approximately ten per academic year). Given our study design and the potential educational benefit offered to residents, we expected 80-90% participation and subsequent enrollment of approximately 40 participants. We intended to recruit as many of the available participants as possible.

Participants

The CONSORT flow diagram is presented in **Figure 1**. We enrolled and randomized 53 participants from July 2019-February 2020. Of the 53 participants enrolled, 1 withdrew consent prior to participation in the study, and 17 were ultimately unable to participate post randomization due to early study closure resulting from the COVID-19 pandemic. All remaining participants from the control (n=22) and intervention groups (n=13) completed the trial and study exit survey. No participant was lost to follow-up, nor was there any crossover between groups.

Table 1. Demographic Characteristics of Study Participants

	Intervention (n =13)	Control (n =22)
Male Sex, n (%)	8 (61.5)	15 (68.2)
Age, median (IQR)	28 (27 - 31)	27 (26 - 30)
Post-Graduate Year, n (%)		
PGY-1	3 (23.1)	5 (22.7)
PGY-2	4 (30.1)	5 (22.7)
PGY-3	3 (23.1)	4 (18.2)
PGY-4	1 (7.7)	4 (18.2)
PGY-5	1 (7.7)	2 (9.1)
CCFP-EM[a]	1 (7.7)	2 (9.1)
Prior Experience, n (%)		
Nursing	0 (0)	2 (9.1)
EMS	0 (0)	0 (0)
ACLS instructor	5 (38.4)	5 (22.7)
Years of Prior Experience, total		
Nursing	0	4
EMS	0	0
ACLS instructor	7	13

IQR = Interquartile range (25th-75th percentile); PGY = post-graduate year; EMS = Emergency Medical Services; ACLS = advanced cardiac life support

[a] CCFP-EM represents residents in their third year of an alternate emergency medicine stream comprised of two years of family medicine and one of focused emergency medicine

Relevant participant baseline characteristics and medical experience are detailed in **Table 1**. Allocation between arms was unequal, with a greater number of participants in the control group. Sex, age, and year of residency were similar between groups. Those with prior relevant experi-

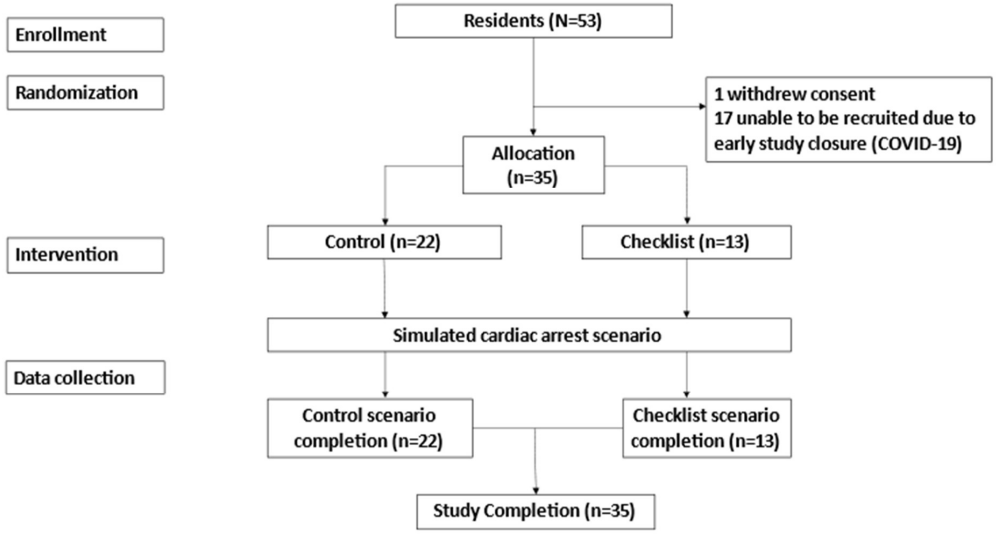

Figure 1. Consort Flow Diagram

ence were similar between arms, with slightly more nursing and ACLS instructor experience in the control group.

RESULTS

Comparison between primary and secondary outcome measures are detailed in **Table 2**. The median proportion (25th-75th IQR) of arrest time elapsed without high-quality compressions was 0.29 (0.23 – 0.36) in the checklist group compared to 0.42 (0.31 – 0.49) in the control group ($p = 0.07$). Participants in the checklist group had significantly lower proportions of time with inadequate compressions and elevated BMV rate (>12 breaths/min), with absolute differences of 18% ($p = 0.03$) and 19% ($p = 0.02$) respectively. There was a significant reduction in total no compression time in the checklist arm ($p < 0.05$). There was no difference between groups regarding number of CPR cycles in which inadequate compressions were identified ($p = 0.55$), or number of prolonged (>10s) pulse checks ($p = 0.94$).

Participants' ability to recognize and correct deficient resuscitation parameters are highlighted in **Table 3**. The proportion of individuals recognizing and correcting poor chest compressions was similar between control and checklist groups ($p = 0.41$). There was a statistically significant difference in recognition of inappropriately rapid BMV, with a greater proportion of individuals in the checklist group making this correction ($p < 0.01$).

We also investigated the impact of the checklist on the number of times participants provided instruction or commentary on target CPR parameters during the scenario. We found a statistically significant ($p < 0.001$) difference in median (IQR) number of verbalizations around these parameters between control [2.5 (2.0-3.8)] and checklist groups [6.0 (4.0-9.0)]. Most participants (10/13) who were given the checklist referenced it during the resuscitation.
Results from study participants' exit survey are presented in **Table 4**. None of the participants reported being aware of the study's objectives or intended measured outcomes, and there were no reported instances of failed participant blinding. Most individuals who received the checklist reported it was easy to understand, useful, and impacted their case management.

DISCUSSION

Interpretation of Findings

In this single-centre randomized controlled trial, we describe the impact of a CPR checklist on achieving resuscitation guideline targets during a simulated cardiac arrest scenario. We did not find a statistically significant difference between groups regarding proportion of total arrest time without high-quality compressions. Those who received the checklist had significant reductions in the proportion of time with inadequate compressions and the proportion of time with unacceptably high BMV rates. The effect sizes on

Table 2. Comparison of CPR Performance Between Control and Intervention Groups

	Control	Checklist	P-Value
Proportion of total arrest time without high-quality compressions[a]	0.42 (0.31-0.49)	0.29 (0.23-0.36)	0.07
Number of CPR cycles in which inadequate compressions were identified[b]	2 (1.25-2)	2 (2-2)	0.55
Proportion of time with inadequate compressions[b]	0.42 (0.33-0.61)	0.24 (0.20-0.38)	0.03
Total no compression time (seconds)	50 (45-56)	47 (41-49)	0.048
Number of pulse checks >10 seconds	0.5 (0-1)	1 (0-1)	0.94
Proportion of time with BMV rate >12 breaths/min	1 (1-1)	0.81 (0.61-1)	0.02

Results reported as median (IQR), p-values from Mann Whitney U Test.
BMV = bag mask ventilation
[a] time without high-quality chest compressions defined as cumulative total of no chest compression time+inadequate chest compression time.
[b] inadequate compressions defined as compressions occurring which do not meet rate and/or depth targets outlined by resuscitation guidelines

Table 3. Odds of Recognizing and Correcting Markers of Poor CPR Quality When Using Checklist

	Proportion of participants correcting in control arm	Proportion of participants correcting in checklist arm	OR (95% CI)	P-value
Chest compressions <100/min	18/22	12/13	2.67 (0.3-26.9)	0.41
BMV >12 breaths/min	1/22	7/13	24.5 (2.5-240.3)	0.006

OR = Odds Ratio; CI = confidence interval; BMV = bag mask ventilation

these outcomes were such that we felt them to be clinically significant. Overall recognition of inadequate chest compressions was similar between groups, but checklist users identified poor performance earlier. We also observed increased communication in the checklist group, suggesting these clinically important improvements in the provision of high-quality CPR were linked to improved communication.

Comparison to Previous Studies

In aviation and operating rooms, checklists have been widely implemented to minimize errors during critical tasks (19,28). As highlighted by Bleetman et al., checklists can improve task performance by: orienting team members to the intended plan, empowering team members to ask critical questions, facilitating the monitoring of vital actions, and identifying errors promptly via the aforementioned mechanisms (29). In the operating room, this has been related to patient-centered outcomes, showing reduced post-operative mortality following institution of pre-surgical checklists (20,21). Checklists have also gained popularity as an adjunct in airway management, showing improved intubation success rate and reduced incidence of complications in both prehospital and emergency department settings (22,23). As it pertains to CPR, checklists have predominately filled an evaluative role, assisting instructors in assessing the adequacy of compressions during training courses (30).

The literature currently supports checklists as beneficial tools, but their application to resuscitation optimization is relatively new. Existing studies around checklist applications to CPR have largely focused on their use as brief educational interventions on improving CPR skills (12,31,32). Our study highlights that most participants in these stressful situations liked having this tool available, and found it changed their management with resultant improvement in clinically relevant outcomes. These findings were in agreement with the work of Arriaga et al. studying checklist application to managing simulated operating room crises (33).

Strengths and Limitations

The COVID-19 pandemic has been a globally disruptive phenomenon. Due to lockdowns of our centre's educational spaces, our study was unfortunately disrupted near the end of completion. This early study closure was unanimously agreed upon by the investigators, as resident safety was of chief concern. Due to the combination of early study closure and randomization occurring at study commencement, group allocation was unequal by chance. This unequal group allocation manifested in greater cumulative prior nursing and ACLS instructor experience in our control group. This, however, would bias our findings towards the null hypothesis and could not invalidate our study findings. Unequal allocation also led to fewer senior residents participating in the study, potentially limiting generalizability of our findings. While our sample size was too small to allow for subgroup analysis, there were no obvious patterns suggesting the benefit seen in the checklist group was driven by junior residents. Finally, as with all simulation studies, despite ensuring a reproducible, high-fidelity environment, caution is required in extrapolating findings to patient care. Despite these limitations, our study was of rigorous methodology and provides preliminary quantitative and qualitative data to support future research of CPR checklists and highlights that simulation is a tool amenable to this investigation.

CONCLUSION

In our simulation-based study, a CPR checklist did not change total time without high-quality compressions. There were clinically and statistically significant reductions in the proportion of time with inadequate chest compressions and duration of inappropriate BMV associated with checklist use. These findings suggest that high-quality CPR checklists may improve resuscitation guideline adherence. The low-cost and low-tech nature of checklists make them easily adoptable and amenable to future investigation. Given this new evidence of potential benefit, further studies are warranted.

Table 4. Insight from Study Exit Surveys

Survey Question	Proportion of participants answering in the affirmative
Were you aware of study outcomes?	0% (0/35)
Was blinding broken?	0% (0/35)
Did you find the checklist useful?	76.9% (10/13)
Did you find the checklist easy to understand?	84.6% (11/13)
Did the checklist change any of your management decisions?	76.9% (10/13)

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Conflicts of Interest Disclosure
There are no conflicts of interest to declare.

Additional Information
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