Clinical paper

The association between CPR quality of In-hospital resuscitation and sex: A hypothesis generating, prospective observational study

Ziv Dadon [a,c], Tal Fridel [b,c], Sharon Einav [b,c,]*

Abstract

Introduction: The relationship between sex and cardiopulmonary resuscitation (CPR) outcomes remains unclear. Particularly, questions remain regarding the potential contribution of unmeasured confounders. We aimed to examine the differences in the quality of chest compression delivered to men and women.

Methods: Prospective study of observational data recorded during consecutive resuscitations occurring in a single tertiary center (Feb-1-2015 to Dec-31-2018) with real-time follow-up to hospital discharge. The studied variables included time in CPR, no-flow-time and fraction, compression rate and depth and release velocity. The primary study endpoint was the unadjusted association between patient sex and the chest compression quality (depth and rate). The secondary endpoint was the association between the various components of chest compression quality, sex, and survival to hospital discharge/neurologically intact survival.

Results: Overall 260 in-hospital resuscitations (57.7% male patients) were included. Among these 100 (38.5%) achieved return of spontaneous circulation (ROSC) and 35 (13.5%) survived to hospital discharge. Female patients were significantly older. Ischemic heart disease and ventricular arrhythmias were more prevalent among males. Compression depth was greater in female vs male patients (54.9 ± 11.3 vs 51.7 ± 10.9 mm; $p = 0.024$). Other CPR quality-metrics were similar. The rates of ROSC, survival to hospital discharge and neurologically intact survival did not differ between males and females. Univariate analysis revealed no association between sex, quality metrics and outcomes.

Discussion: Women received deeper chest compressions during in-hospital CPR. Our findings require corroboration in larger cohorts but nonetheless underscore the need to maintain high-quality CPR in all patients using real-time feedback devices. Future studies should also include data on ventilation rates and volumes which may contribute to survival outcomes.

Keywords: Cardiopulmonary resuscitation, Return of spontaneous circulation, Heart arrest, Mortality, Sex characteristics

Introduction

The relationship between sex and cardiopulmonary resuscitation (CPR) outcomes remains controversial.[1–2] Women undergoing CPR have less favorable Utstein elements than men;[3] they are older,[4] they present with less shockable rhythm,[5] their arrest occurs more frequently at home, is less commonly witnessed and resultantly they are less likely to receive bystander CPR.[6–8] Despite these poor predictors, most studies report higher rates of return of spontaneous circulation (ROSC) and survival to admission among women undergoing CPR.[9–14]

However, most studies also report that these advantages are lost during hospitalization; women have unfavorable longer-term out-

comes including lower unadjusted rates of survival to hospital discharge, a finding often attributed to older age and a higher burden of co-morbidities.[7,12–18] Indeed, younger women seem to have an ongoing survival advantage.[12,15,19] However, in many studies, after adjusting for pre-hospital variables, women seem to lose their initial survival advantage.[7,11,18,20–23] Furthermore, female survivors often have lower rates of neurologically intact survival and seem to suffer poorer long-term quality of life compared to men.[24–27] Unlike the well-established data on sex differences regarding out-of-hospital cardiac arrest (OHCA), there are conflicting results when addressing in-hospital cardiac arrest (IHCA).[28–32]

Research on the difference in survival between men and women after resuscitation has focused mainly on patient characteristics (e.g. patient age, and background diseases) and overt event characteristics (e.g. witnessed status, presenting rhythm, bystander CPR). What remains relatively unknown is whether patient outcome is also affected by variables less evident such as the quality of CPR itself and the post-resuscitation care provided to men and women.[23,33–34]

High quality CPR may be associated with higher rates of ROSC and improved survival to hospital discharge.[35–36] Several studies have shown that increasing chest compression rate is associated with higher rates of ROSC,[37–38] and with improved survival to hospital discharge.[39] However, increased compression rate is also inversely related to depth of chest compression. Chest wall compliance may differ between men and women given established anatomical differences,[40–41] which may also affect chest compression quality.

This study aimed to describe the quality of chest compression received by male and female patients during IHCA. As a secondary outcome we also conducted a preliminary examination of the relation between quality metrics and outcomes in men and women. We hypothesized that men more commonly receive good quality chest compression than do women. This may ultimately lead to the higher rates of survival to hospital discharge and better neurological outcomes observed among men.

Methods

Study design

Prospective observational study of data recorded during consecutive resuscitations (real-time recordings) accompanied by real time patient follow-up after the event. The study was approved by the Institutional Review Board (IRB) committee with waiver of informed consent (IRB p4.15). We report our findings in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) and the Reporting of studies Conducted using Observational Routinely-collected Data (RECORD) statement.[42–43]

Clinical setting

Tertiary medical center with > 1,000 admission beds and the largest department of emergency medicine in the district, receiving ~ 170,000 adult referrals annually. The hospital staff undergo routine bi-annual accreditation in CPR as required by the Joint Commission Resources (JCR) and the Israel Ministry of Health. CPR is performed in accordance with International Liaison Committee of Resuscitation (ILCOR) recommendations. Resuscitation events are mandatorily reported on a standardized electronic form embedded within the electronic medical records (EMRs) of the patients. In-hospital protocols also include routine targeted tempera-

ture management (below 36 °C) and percutaneous coronary intervention when indicated.

Study population

All patients aged ≥ 18 years who underwent cardiac arrest and CPR between February 1, 2015 through December 31, 2018 were screened for inclusion. Consistent with Utstein-style registry guidelines,[44] only the index event was included for patients with multiple arrests.

Patients with a valid do not attempt resuscitation (DNAR) order at the time of arrest, those with a terminal disease precluding provision of full resuscitation efforts, those with a traumatic arrest, cases with mechanical chest compression involvement (including AutoPulse® Resuscitation System and LUCAS™ Chest Compression System), those with no compressions and cases with poor-quality defibrillator recordings precluding analysis were excluded.

Data sources

All in-hospital resuscitations are documented in the electronic medical record (EMR) using an online form based on the Utstein guidelines for reporting of CPR.[44] All resuscitations are also reported in real time to a dedicated research nurse as part of an ongoing quality-improvement project initiated by the hospital resuscitation committee. The nurse ensures completion of the resuscitation report as required, follows the patient until hospital discharge and evaluates neurological outcome at discharge.

Two types of data are routinely collected: Patient data and resuscitation events. Patient data are collected in real time in the EMR. For the purpose of this study we accessed demographic details, medical history, baseline Cerebral Performance Category (CPC), arrest characteristics, post-resuscitation care and outcomes. Resuscitation events are recorded using ZOLL® R Series® defibrillators. Event recordings are transmitted through the hospital wireless system to the hospital CodeNet Central™ and managed by a study nurse.

Data management is further detailed in Supplementary Fig. 1.

Study variables

Our primary study aim was to describe the unadjusted association between patient sex and the quality of chest compression (depth and rate) delivered. Secondary aims included a description of the associations between the quality of chest compression (including resuscitation time, no-flow-time and fraction, compression rate, compression depth and release velocity) and male and female survival to hospital discharge and neurologically intact survival (CPC 1–2) after in-hospital cardiac arrest.

Presenting rhythm (the first rhythm recorded), time in CPR, no-flow-time (NFT) and fraction (NFF), compression rate, compression depth, mean release velocity, total compressions and number of shocks delivered were derived from the defibrillator file.

Management of quantitative variables

NFT was calculated as the time in chest compression subtracted from arrest-to-ROSC time. NFF was calculated by dividing NFT by the total time in CPR. Compression depth was classified as appropriate between 50–60 mm and rate was classified as appropriate between 100–120 compressions per minute (CPM) as per guidelines.[45] Both variables are described as percent within recommended range- together and separately. Mean compression depths and rates were calculated only from recorded chest compressions; periods without chest compression (i.e. chest compression "0") were not
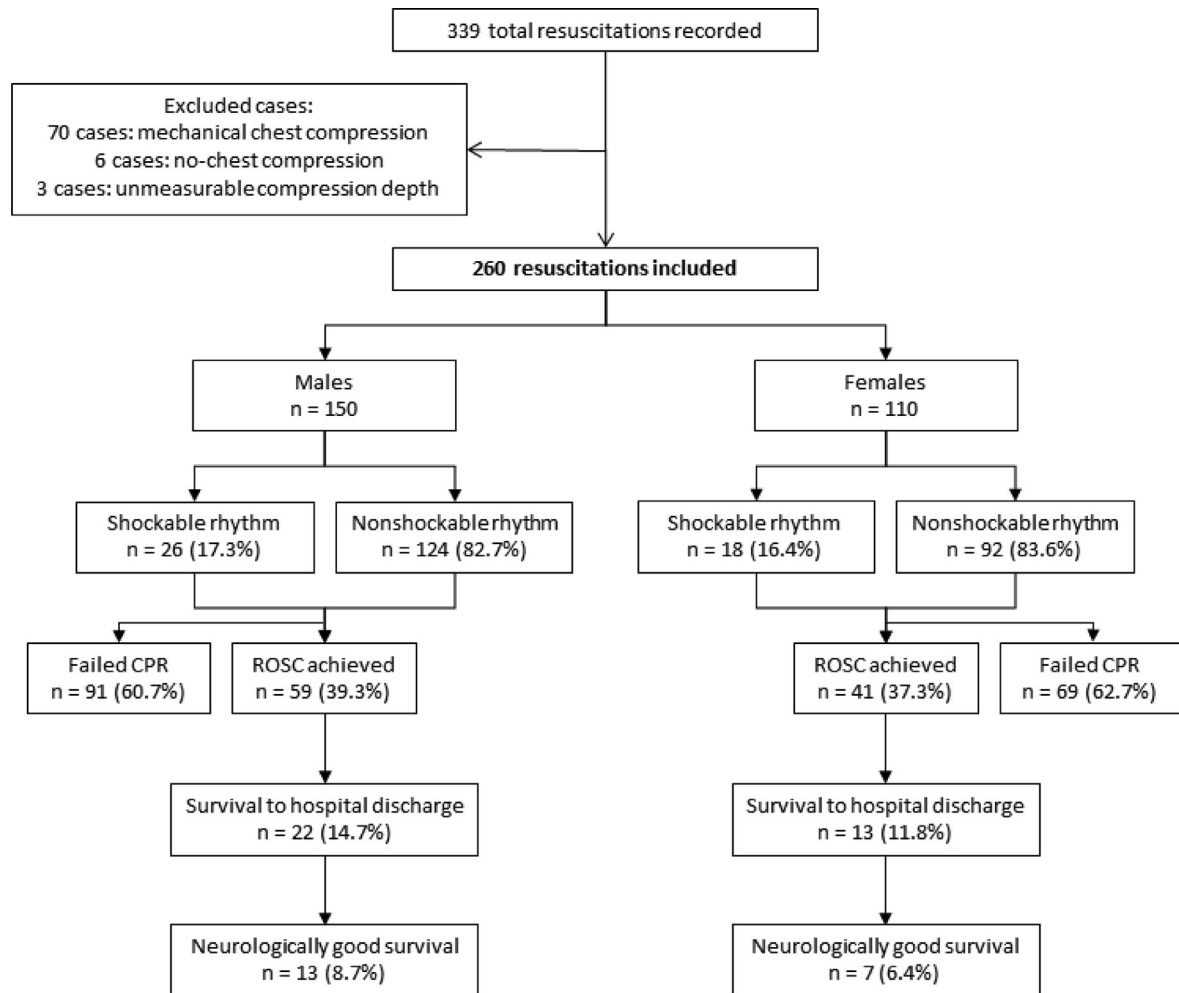
Fig. 1 – Flow chart of inclusion/exclusion criteria and patients' outcomes. * Cases in which mechanical chest compression was involved, including AutoPulse® (n = 66) and LUCAS™ (n = 20) compression systems, were excluded (both devices were used in 16 patients). <u>Abbreviations</u>: CPR, cardiopulmonary resuscitation; ROSC, return of spontaneous circulation.

included in the calculation. CPC was grouped to intact neurological outcome (category 1–2) and poor-neurological outcome plus death (categories 3–5) for CPC outcome analysis.

Statistical analyses

Lacking prior data on the topic sample size calculations were not performed a-priori. Instead, we calculated post-hoc how many patients would be required for a multicenter study on the topic based on our findings using Power and Sample Size software (version 3.1.2. NCSS, LLC, Utah). We first examined study population characteristics, quality metrics and outcomes using descriptive statistics (i.e. numbers, proportions, means with their standard deviations, median and interquartile-ranges). Associations between dichotomous variables were studied using either the Chi-square or the Fisher exact test as required. The t-test or Mann-Whitney U test were used for comparisons of normally distributed and non-normally distributed continuous variables, respectively. Associations with outcomes were studied using logistic regression but are not presented in the body of the manuscript as this was not our study aim. For further details regarding this analysis see Supplementary Note 1. Statistical analyses were performed using SPSS Statistics for Windows version 21

(SPSS Inc., Chicago, IL). All tests were two-sided and a p value < 0.05 was considered statistically significant.

Results

During the study period, 339 in-hospital resuscitations were recorded. Among these, 79 were excluded, leaving 260 patients for inclusion in the analysis (Fig. 1).

The mean age of the included cohort was 75.75 ± 15.9 years. The most common preexisting comorbidities were hypertension (73.8 %) and diabetes mellitus (48.8 %). In terms of cardiovascular comorbidities, 58.8 % of the patients had prior congestive heart failure, 44.6 % had ischemic heart disease (IHD), 38.9 % had a history of arrhythmias, and 23.4 % a history of stroke (Table 1). Among the 260 cases, overall 100 achieved ROSC and 35 (13.5 %) survived to hospital discharge (Fig. 1).

Comparison between men and women

Most of the patients (n = 150, 57.7 %) were male. Females were significantly older than males with a mean 4.7-year difference

Table 1 – Patient demographics, medical history and event characteristics.

Variable	Available data	All patients (n = 260)	Groups		
			Male (n = 150)	Female (n = 110)	p-value
Demographics and medical history					
Age (mean ± SD)	260/260	75.75 ± 15.8	73.77 ± 16.1	78.45 ± 15.2	**0.018**
Hypertension, n (%)	249/260	192 (73.8)	110 (73.3)	82 (74.5)	0.58
IHD, n (%)	253/260	116 (44.6)	83 (55.3)	33 (30.0)	**<0.001**
CHF, n (%)	249/260	127 (48.8)	74 (49.3)	53 (48.2)	0.79
Arrhythmias, n (%)	246/260	101 (38.8)	58 (38.7)	43 (39.1)	0.98
Arrhythmias, specific	246/260				
Atrial, n (%)		91 (35.0)	48 (32.0)	43 (39.1)	0.29
Ventricular, n (%)		8 (3.1)	8 (5.3)	0	**0.012**
Both, n (%)		2 (0.8)	2 (1.3)	0	0.51
Diabetes mellitus, n (%)	253/260	127 (48.8)	68 (45.3)	59 (53.6)	0.18
CVA, n (%)	249/260	61 (23.4)	38 (25.3)	23 (20.9)	0.42
Prior CPC of 1–2, n (%)	256/260	185 (71.2)	112 (74.7)	73 (66.4)	0.22
Prior CPC	256/260				0.08
CPC 1, n (%)		116 (44.6)	77 (51.3)	39 (35.5)	
CPC 2, n (%)		69 (26.5)	35 (23.3)	34 (30.9)	
CPC 3, n (%)		69 (26.5)	36 (24.0)	33 (30.0)	
CPC 4, n (%)		2 (0.8)	1 (0.7)	1 (0.9)	
Event characteristics					
Arrest location	225/260				0.97
Ward, n (%)		165 (63.5)	93 (62.0)	72 (65.5)	
ED, n (%)		60 (23.1)	34 (22.7)	26 (23.6)	
Arrest shift	224/260				0.68
Morning, n (%)		66 (25.4)	39 (26.0)	27 (24.5)	
Afternoon, n (%)		67 (25.8)	39 (26.0)	28 (25.5)	
Night, n (%)		91 (35.0)	48 (32.0)	43 (39.1)	
Weekend arrest, n (%)	260/260	51 (19.6)	25 (16.7)	26 (23.7)	0.16
Witnessed arrest, n (%)	255/260	168 (64.6)	98 (65.3)	70 (63.6)	0.76
Presenting rhythm	258/260				0.30
VT/VF, n (%)		44 (16.9)	26 (17.3)	18 (16.4)	
PEA, n (%)		79 (30.4)	48 (32.0)	31 (28.2)	
Asystole, n (%)		87 (33.5)	43 (28.7)	44 (40.0)	
Other, n (%)		48 (18.5)	31 (20.7)	17 (15.5)	
No. of shocks delivered	260/260				0.17
Mean ± SD		1.07 ± 3.3	1.23 ± 3.8	0.85 ± 2.3	
Median (IQR)		0 (0–1)	0 (0–1)	0 (0–1)	
CPR duration (min.)	260/260				0.45
Mean ± SD		15.8 ± 12.3	16.3 ± 13.5	15.1 ± 10.5	
Median (IQR)		13.4 (7.5–20.5)	13.4 (7.7–20.4)	13.2 (7.3–20.3)	

Abbreviations: %, percent; CHF, congestive heart failure; CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; CVA, cerebrovascular accident; ED, emergency department; IHD, ischemic heart disease; IQR, interquartile range; min., minutes; n/no., number; PEA, pulseless electrical activity; SD, standard deviation; VF, ventricular fibrillation; VT, ventricular tachycardia.

(p = 0.018). Males had a higher prevalence of IHD (55.3 % vs 30.0 %, p < 0.001) and ventricular arrhythmias (5.3 % vs 0.0 %, p = 0.012). No other difference was observed in comorbidities and the characteristics of the arrest itself also did not differ between males and females (Table 1).

With regards to quality metrics, as shown in Table 2, the depth of compression was greater in female patients (mean: 54.9 ± 11.3 mm, median: 54.8 mm vs mean: 51.7 ± 10.9 mm, median: 52.6 mm; p = 0.024) but no other differences were observed (the distribution of recorded compression depths is shown in Supplementary Fig. 2, compression rates in Supplementary Fig. 3, NFTs in Supplementary Fig. 4 and NTTs in Supplementary Fig. 5).

Based on our finding of a 0.5 cm difference in the mean depth of chest compression in women and men and a normal distribution of compression depth with a standard deviation of ± 10 cm and a pro-portion of 1:1.5 females to males, we calculated that overall 7898 men and 5213 women would need to be studied to reject the null hypothesis that the mean compression depth in the two groups is equal with a probability (power) of 0.8 and a type I error of 0.05.

The in-hospital treatment of males and female patients was similar and the rates of ROSC, survival to hospital discharge and neurologically intact survival also did not differ between males and females (Table 3).

In summary, men and women differed in the rates of IHD, ventricular arrhythmias and in compression depth. These were therefore selected for inclusion in the models as well as sex.

The association between sex and survival to hospital discharge is presented in Supplementary Table 1A. The association between sex and neurologically intact survival is presented in Supplementary Table 1B.

Table 2 – Cardiopulmonary resuscitation quality metrics.

Variable	All patients (n = 260)	Groups		
		Male (n = 150)	Female (n = 110)	p-value
Comp. rate (cpm)				0.43
Mean ± SD	124.6 ± 14.5	125.2 ± 13.9	123.8 ± 15.2	
Median	124.4	124.2	124.9	
IQR	114.2–132.7	114.6–133.8	113.8–131.5	
Comp. depth (mm)				**0.024**
Mean ± SD	53.1 ± 11.2	51.7 ± 10.9	54.9 ± 11.3	
Median	53.7	52.6	54.8	
IQR	46.2–60.3	45.2–58.0	48.7–61.8	
NFT (sec)				0.86
Mean ± SD	231.9 ± 312.5	234.9 ± 332.3	227.8 ± 284.6	
Median	128.5	125.5	146.6	
IQR	54.0–270.9	65.0–268.3	49.5–276.5	
NFF (%)				0.83
Mean ± SD	22.7 ± 16.3	22.9 ± 16.7	22.5 ± 15.7	
Median	18.4	17.6	19.2	
IQR	11.4–29.3	11.0–30.0	12.3–27.3	
Comp. rate in target (%)				0.79
Mean ± SD	34.1 ± 26.3	33.7 ± 26.6	34.6 ± 26.0	
Median	30.4	30.2	32.2	
IQR	11.0–53.6	10.4–53.9	11.7–53.4	
Comp. depth in target (%)				0.64
Mean ± SD	26.3 ± 15.8	25.9 ± 14.9	26.9 ± 16.9	
Median	25.8	25.8	25.8	
IQR	14.8–36.8	15.8–35.5	12.7–40.1	
Comb. comp. in target (%)				0.41
Mean ± SD	9.0 ± 10.5	8.6 ± 10.2	9.7 ± 10.9	
Median	5.7	5.3	5.9	
IQR	0.7–13.6	0.6–12.8	0.8–15.0	
Release velocity (mm/s)				0.84
Mean ± SD	335.2 ± 80.8	334.3 ± 78.3	336.3 ± 84.5	
Median	334.6	336.1	333.7	
IQR	281.0–382.8	280.2–376.6	283.3–385.5	

• Data was available for all patients.

Abbreviations: %, percent; comb., combined; comp., compression; cpm, compressions per minute; IQR, interquartile range; min, minutes; mm, millimeter; NFF, no-flow fraction; NFT, no-flow time; SD, standard deviation; sec, seconds.

Table 3 – In-hospital treatment, hospital treatment, lengths of stay and outcomes.

Variable	Available data	Male (n = 150)	Female (n = 110)	p-value
ROSC, n (%)	260/260	59 (39.3)	41 (37.3)	0.74
Survival to hospital discharge, n (%)	260/260	22 (14.7)	13 (11.8)	0.51
Discharge CPC	260/260			0.49
1–2, n (%)		13 (8.7)	7 (6.4)	
3–5, n (%)		137 (91.3)	103 (93.6)	
		Male (n = 59)	**Female (n = 41)**	
TTM, n (%)	100/100	3 (5.1)	0 (0.0)	0.29
PCI, n (%)	100/100	12 (20.3)	4 (9.8)	0.25
Post CPR LOS (d)	100/100			0.75
Mean ± SD		15.3 ± 18.2	16.6 ± 20.9	
Median (IQR)		8 (2.0–25.0)	5 (1–27.5)	
		Male (n = 22)	**Female (n = 13)**	
Survivors to hospital discharge LOS (d)	35/35			0.12
Mean ± SD		27.3 ± 20.5	39.5 ± 21.7	
Median (IQR)		25.0 (7.5–40.0)	34.0 (22.0–62.0)	

Abbreviations: %, percent; CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; d, days; IQR, interquartile range; LOS, length of stay; n, number; PCI, percutaneous coronary intervention; ROSC, return of spontaneous circulation; SD, standard deviation; TTM, targeted temperature management.

Discussion

This hypothesis-driving study evaluated the quality of chest compression in female and male patients during in-hospital CPR in a single medical center. The depth of compression was higher in female patients, but no other differences were observed in quality metrics and outcomes. Variable distribution suggests that that a much larger cohort would be required to validate this finding.

In the present study the median compression depth (53.7 cm) and NFF (0.18) were well within those recommended by the American Heart Association (AHA) whereas the median rate was higher (124.4 CPM).[45] Previous data studying IHCA quality metrics are scarce but in the existing reports the median depths ranged between 44.7 and 63.4 cm, the median NFFs ranged between 0.06 and 0.13 and the median rate ranged between 108.6 and 114 CPM.[46–48] The duration of CPR was slightly shorter in the current study than that reported by the Get-with-the-Guidelines-Resuscitation (GWTG-R) registry (median of 13.4 vs 17 minutes, respectively). This difference may stem from different methods of time collection; in the current study resuscitation times were taken from defibrillator recordings, whereas in the GWTG-R they were derived from the resuscitation report.[30]

Differences in the depth of chest compression may be attributed to anatomical differences between the sexes which likely affect chest wall compliance. The thoraxes of men and women differ in several structural characteristics. Women have significantly lower rib maximum bending moments (rotational force occurring when a force is applied perpendicularly to a structure), lower rib slopes of bending moment–angle curves, and thicker average rib cortical-bone.[49] Also, women have smaller radial rib-cage dimensions relative to their height, and a greater anterior-posterior inclination of the ribs.[41] all of which can potentially increase chest wall compliance to compression. On the other hand, women, on average, have thicker chest walls than men.[40] The implications of each of these differences for the quality of chest compression not entirely clear but they may have played a role in the deeper chest compressions observed in female patients. This assumption is supported by the finding that deeper chest compression did not translate to a difference in the rate of compression, suggesting that fatigue is probably not the sole cause for this finding.

The preponderance of studies describe higher rates of ROSC and survival to admission among women compared to men when undergoing OHCA with CPR.[9–13] This occurs despite less favorable demographic and event characteristics (e.g. older age, less shockable rhythm, less public arrest locations, less witnessed arrests and less layperson CPR.[3–7] This apparent paradox remains poorly understood and several etiologies have been suggested for this difference. Some researchers have suggested that female endogenous hormones, estrogen and progesterone, provide an explanation for the female survival advantage.[9,11] Experimental and clinical studies of the effects of estrogen have demonstrated a plethora of cardiac and neuroprotective effects.[50–51] Confirmation to this theory may be found in the higher prevalence of IHD among male patients (as also shown in the present study). However, this explanation has been challenged as the cardiac protection provided by estrogen is mainly relevant to premenopausal women, whereas a higher rate of ROSC in women has been observed across all age groups in OHCA.[11–13,19,50] Furthermore, the advantage of hormonal protection should remain consistent across arrest locations, OHCA and IHCA yet it is repeatedly stronger in OHCA. Our study differs from most previous studies as it includes IHCA CPR. Previous studies examining the association of

sex with ROSC amongst other outcomes after IHCA had conflicting results.[19,28–31] The lack of difference in survival and intact neurological outcome rates observed in our study may be a true finding but it may also stem from the small number of survivors. Univariate analysis also revealed an association between a higher percentage of compression depth in target and a lower likelihood of neurologically intact survival. In the setting of low rates of withdrawal of care, high quality compressions may have led better rates of ROSC and survival despite early irreversible neurological damage.

Our finding provides a plausible explanation for women's better short-term outcomes as well as the difference in OHCA vs IHCA. Although both sexes received chest compressions > 5 cm in depth according to current guidelines, deeper compressions may still lead to better cardiac output, especially as the compressions delivered to male patients were in the lower limit of the recommendations. If prehospital emergency medical services teams encounter cardiac arrest more commonly, the quality of CPR may be more consistent in the prehospital setting, thereby allowing other differences to manifest.

In our study the rate of ROSC did not differ between men and women. This could be explained by selection bias; sex may affect the decision to perform CPR.[52] Baseline population differences may obscure performance bias in either direction. Several studies have reported that women have unfavorable long-term outcomes after resuscitation, including significantly lower unadjusted rates of survival to hospital discharge.[7,12–18] It remains to be seen whether the initial survival advantage seen elsewhere is related to more effective chest compression in women in the prehospital setting. Such an advantage could easily be lost if women also have more neurological damage as a result of a larger proportion of time with no flow at all and would align with descriptions of less efficacious care received by women receive during hospital admission following arrest.[53–56]

Our rates of ROSC and survival to hospital discharge were relatively low (38.5 % and 13.5 %, respectively). Other IHCA trials report ROSC rates of 50.4 %–51.3 % and survival rates of 20.6 %–42.2 %.[28–32] Our cohort was older than those reported elsewhere,[28,30–31] which may account for our relatively poor outcomes despite reasonable quality of CPR. Our cohort also had a low proportion of initial shockable rhythms (16.9 %) which may indicate late discovery in a chronically understaffed public medical system.

Limitations

Our study was restricted to a single site. Populations and the quality of resuscitation may differ between hospitals. This may limit the generalizability of our findings. However, as mentioned above, our outcomes were overall similar to those observed in prior publications from the National Registry of Cardiopulmonary Resuscitation (NRCPR).[57] The number of patients studied was small, but hypothesis generating studies require only a finding with a plausible explanation. We also did not study all the components of high-quality CPR (e.g. ventilation was not appraised). Despite our prospective methodology bias may also exist in our data. In order to minimize incomplete reporting and documentation bias, relevant hospital staff underwent training in report completion, both before and during the study. Interviews were also conducted in "hot pursuit" with those on location at the time of the event. Missing data are reported in the tables. Rescuer awareness of study conduction (i.e. the "Hawthorne effect")[58] may have affected the overall quality of resuscitation but this effect was unlikely to differ between sexes as the rescuers were unaware

of the study aim. We also do not report the cause of arrest, which may also differ between the sexes. Finally, the research nurse who analysed the recordings was blinded to patient sex and outcome and those treating the patients were blinded to the recordings.

Conclusions

In this study women received deeper chest compression. Sample size calculations suggest this difference is probably not the only reason for the survival difference seen in men and women, but it may contribute to these differences. Conservative interpretation suggests there is a need to maintain high-quality CPR in all patients using real-time feedback devices. Additional studies are needed to confirm our findings in other settings. Larger cohorts should also serve to examine whether differing CPR quality between men and women is associated with unfavorable outcomes.

CRediT authorship contribution statement

Ziv Dadon: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Tal Fridel:** Formal analysis, Investigation, Writing – original draft. **Sharon Einav:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2022.100280.

Author details

[a]Jesselson Integrated Heart Center, Jerusalem, Israel   [b]Intensive Care Unit, Shaare Zedek Medical Center, Jerusalem, Israel[c]Faculty of Medicine Hebrew University, Jerusalem, Israel

REFERENCES

1. Wigginton JG, Perman SM, Barr GC, et al. Sex- and gender-specific research priorities in cardiovascular resuscitation: proceedings from the 2014 Academic Emergency Medicine Consensus Conference Cardiovascular Resuscitation Research Workgroup. Acad Emerg Med 2014;21:1343–9. PMID: 25491706.
2. King BM. Point: a call for proper usage of "gender" and "sex" in biomedical publications. Am J Physiol Regul Integr Comp Physiol 2010;298:R1700–1. PMID: 20357018.
3. Cummins RO, Chamberlain DA, Abramson NS, et al. Recommended guidelines for uniform reporting of data from out-of-hospital cardiac arrest: the Utstein Style. A statement for health professionals from a task force of the American Heart Association, the European Resuscitation Council, the Heart and Stroke Foundation of Canada, and the Australian Resuscitation Council. Circulation 1991;84:960–75. PMID: 1860248.
4. Piegeler T, Thoeni N, Kaserer A, et al. Sex and Age Aspects in Patients Suffering From Out-Of-Hospital Cardiac Arrest: A Retrospective Analysis of 760 Consecutive Patients. Medicine 2016;95:e3561. PMID: 27149475.
5. Holmgren C, Bergfeldt L, Edvardsson N, et al. Analysis of initial rhythm, witnessed status and delay to treatment among survivors of out-of-hospital cardiac arrest in Sweden. Heart 2010;96:1826–30. PMID: 20889992.
6. Adielsson A, Hollenberg J, Karlsson T, et al. Increase in survival and bystander CPR in out-of-hospital shockable arrhythmia: bystander CPR and female gender are perdictors of improved outcome. Experiences from Sweden in an 18-yearperspective. Heart 2011;97:1391–6. PMID: 21715444.
7. Kim C, Fahrenbruch CE, Cobb LA, Eisenberg MS. Out-of-hospital cardiac arrest in men and women. Circulation 2001;104:2699–703. PMID: 11723022.
8. Blewer AL, McGovern SK, Schmicker RH, et al. Gender disparities among adult recipients of bystander cardiopulmonary resuscitation in the public. Circ-Cardiovasc Qual 2018;11:e004710. PMID: 30354377.
9. Hasan OF, Al Suwaidi J, Omer AA, et al. The influence of female gender on cardiac arrest outcomes: a systematic review of the literature. Curr Med Res Opin 2014;30:2169–78. PMID: 24940826.
10. Mahapatra S, Bunch TJ, White RD, Hodge DO, Packer DL. Sex differences in outcome after ventricular fibrillation in out-of-hospital cardiac arrest. Resuscitation 2005;65:197–202. PMID: 15866401.
11. Pell JP, Sirel J, Marsden AK, Cobbe SM. Sex differences in outcome following community-based cardiopulmonary arrest. Eur Heart J 2000;21:239–44. PMID: 10639306.
12. Morrison LJ, Schmicker RH, Weisfeldt ML, et al. Effect of gender on outcome of out of hospital cardiac arrest in the Resuscitation Outcomes Consortium. Resuscitation 2016;100:76–81. PMID: 26705971.
13. Kitamura T, Iwami T, Nichol G, et al. Reduction in incidence and fatality of out-of-hospital cardiac arrest in females of the reproductive age. Eur Heart J 2015;31:1365–72. PMID: 20231155.
14. Bougouin W, Mustafic H, Marijon E, et al. Gender and survival after sudden cardiac arrest: a systematic review and meta-analysis. Resuscitation 2015;94:55–60. PMID: 26143159.
15. Akahane M, Ogawa T, Koike S, et al. The effects of sex on out-of-hospital cardiac arrest outcomes. Am J Med 2011;124:325–33. PMID: 21435423.
16. Wissenberg M, Hansen CM, Folke F, et al. Survival after out-of-hospital cardiac arrest in relation to sex: a nationwide registry-based study. Resuscitation 2014;85:1212–8. PMID: 24960430.
17. Karlsson V, Dankiewicz J, Nielsen N, et al. Association of gender to outcome after out-of-hospital cardiac arrest–a report from the International Cardiac Arrest Registry. Crit Care 2015;19:182. PMID: 25895673.
18. Bray JE, Stub D, Bernard S, Smith K. Exploring gender differences and the "oestrogen effect" in an Australian out-of-hospital cardiac arrest population. Resuscitation 2013;84:957–63. PMID: 23246988.
19. Topjian AA, Localio AR, Berg RA, et al. Women of child-bearing age have better inhospital cardiac arrest survival outcomes than do equal-aged men. Crit Care Med 2010;38:1254–60. PMID: 20228684.
20. Lindgren E, Östlund O, Rubertsson S. Gender differences in outcome and post resuscitation care after out-of-hospital cardiac arrest. Analysis of the LINC trial. Resuscitation 2015;96:101.
21. Ritter G, Wolfe RA, Goldstein S, et al. The effect of bystander CPR on survival of out-of-hospital cardiac arrest victims. Am heart J 1985;110:932–7. PMID: 4061266.

22. Perers E, Abrahamsson P, Bång A, et al. There is a difference in characteristics and outcome between women and men who suffer out of hospital cardiac arrest. Resuscitation 1999;40:133–40. PMID: 10395395.

23. Bosson N, Kaji AH, Fang A, et al. Sex Differences in Survival From Out-of-Hospital Cardiac Arrest in the Era of Regionalized Systems and Advanced Post-Resuscitation Care. J Am Heart Assoc 2016;5: e004131. PMID: 27633392.

24. Wachelder EM, Moulaert VR, van Heugten C, Verbunt JA, Bekkers SC, Wade DT. Life after survival: long-term daily functioning and quality of life after an out-of-hospital cardiac arrest. Resuscitation 2009;80:517–22. PMID: 19282084.

25. Bougouin W, Dumas F, Marijon E, et al. Gender differences in early invasive strategy after cardiac arrest: Insights from the PROCAT registry. Resuscitation 2017;114:7–13. PMID: 28216090.

26. Winther-Jensen M, Hassager C, Kjaergaard J, et al. Women have a worse prognosis and undergo fewer coronary angiographies after out-of-hospital cardiac arrest than men. Eur Heart J Acute Cardiovasc Care 2018;7:414–22. PMID: 29064270.

27. Lei H, Hu J, Liu L, Xu D. Sex differences in survival after out-of-hospital cardiac arrest: a meta-analysis. Crit Care 2020;24:1–3. PMID: 33076963.

28. Herlitz J, Rundqvist S, Bång A, et al. Is there a difference between women and men in characteristics and outcome after in hospital cardiac arrest? Resuscitation 2001;49:15–23. PMID: 11334687.

29. Fugate JE, Brinjikji W, Mandrekar JN, et al. Post-Cardiac Arrest Mortality Is Declining: A Study of the US National Inpatient Sample 2001 to 2009. Circulation 2012;126:546–50. PMID: 22740113.

30. Khan AM, Kirkpatrick JN, Yang L, Groeneveld PW, Nadkarni VM, Merchant RM. Age, sex, and hospital factors are associated with the duration of cardiopulmonary resuscitation in hospitalized patients who do not experience sustained return of spontaneous circulation. J Am Heart Assoc 2014;3:e001044. PMID: 25520328.

31. Kazaure HS, Roman SA, Sosa JA. Epidemiology and outcomes of in-hospital cardiopulmonary resuscitation in the United States, 2000–2009. Resuscitation 2013;84:1255–60. PMID: 23470471.

32. Rohlin O, Taeri T, Netzereab S, Ullemark E, Djärv T. Duration of CPR and impact on 30-day survival after ROSC for in-hospital cardiac arrest—a Swedish cohort study. Resuscitation 2018;132:1–5. PMID: 30138650.

33. Kim MJ, Shin SD, McClellan WM, et al. Neurological prognostication by gender in out-of-hospital cardiac arrest patients receiving hypothermia treatment. Resuscitation 2014;85:1732–8. PMID: 25281187.

34. Slater M, Sparrow-Downes VM, Veigas P, Bielecki JM, Rac VE. Gender differences in the provision of key post-arrest interventions for out-of-hospital cardiac arrest (OHCA) patients-protocol for a systematic review. Syst Rev 2019;8:1–5. PMID: 31409393.

35. Edelson DP, Abella BS, Kramer-Johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006;71:137–45. PMID: 16982127.

36. Stiell IG, Brown SP, Nichol G, et al. What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? Circulation 2014;130:1962–70. PMID: 25252721.

37. Idris AH, Guffey D, Aufderheide TP, et al. Relationship between chest compression rates and outcomes from cardiac arrest. Circulation 2012;125:3004–12. PMID: 22623717.

38. Wallace SK, Abella BS, Becker LB. Quantifying the effect of cardiopulmonary resuscitation quality on cardiac arrest outcome: a systematic review and meta-analysis. Circ Cardiovasc Qual Outcomes 2013;6:148–56. PMID: 23481533.

39. Idris AH, Guffey D, Pepe PE, et al. Chest compression and survival following out-of-hospital cardiac arrest. Crit Care Med 2015;43:840–8. PMID: 25565457.

40. Givens ML, Ayotte K, Manifold C. Needle thoracostomy: implications of computed tomography chest wall thickness. Acad Emerg Med 2004;11:211–3. PMID: 14759970.

41. Romei M, Mauro AL, D'Angelo MG, et al. Effects of gender and posture on thoraco-abdominal kinematics during quiet breathing in healthy adults. Respir Physiol Neurobiol 2010;172:184–91. PMID: 20510388.

42. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. STROBE Initiative; The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 2008;61:344–9. PMID: 25046131.

43. Benchimol EI, Smeeth L, Guttmann A, et al. RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. PLoS Med 2015;12:e1001885. PMID: 26440803.

44. Nolan JP, Berg RA, Andersen LW, et al. Cardiac arrest and cardiopulmonary resuscitation outcome reports: update of the Utstein resuscitation registry template for in-hospital cardiac arrest: a consensus report from a task force of the international Liaison committee on resuscitation (American heart association, European resuscitation Council, Australian and New Zealand Council on resuscitation, heart and stroke foundation of Canada, InterAmerican heart foundation, resuscitation Council of southern africa, resuscitation Council of asia). Circulation 2019;140:e746–57. PMID: 31522544.

45. Panchal AR, Bartos JA, Cabañas JG, et al. Part 3: adult basic and advanced life support: 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2020;142:S366–468. PMID: 33081529.

46. Sheak KR, Wiebe DJ, Leary M, et al. Quantitative relationship between end-tidal carbon dioxide and CPR quality during both in-hospital and out-of-hospital cardiac arrest. Resuscitation 2015;89:149–54. PMID: 25643651.

47. Sutton RM, French B, Niles DE, et al. 2010 American Heart Association recommended compression depths during pediatric in-hospital resuscitations are associated with survival. Resuscitation 2014;85:1179–84. PMID: 24842846.

48. Losert H, Sterz F, Köhler K, et al. Quality of cardiopulmonary resuscitation among highly trained staff in an emergency department setting. Arch Intern Med 2006;166:2375–80. PMID: 17130392.

49. Kalra A, Saif T, Shen M, et al. Characterization of human rib biomechanical responses due to three-point bending. Stapp car crash J 2015;59:113. PMID: 26660742.

50. Knowlton AA, Korzick DH. Estrogen and the female heart. Mol Cell Endocrinol 2015;389:31–9. PMID 24462775.

51. Shao B, Cheng Y, Jin K. Estrogen, neuroprotection and neurogenesis after ischemic stroke. Curr Drug Targets 2012;13:188–98. PMID: 22204318.

52. Goodlin SJ, Zhong Z, Lynn J, et al. Factors associated with use of cardiopulmonary resuscitation in seriously ill hospitalized adults. JAMA 1999;282:2333–9. PMID: 10612321.

53. Herzog E, Tamis J, Aziz EF, Shapiro JM. A novel program focused on women survivors who were enrolled in a cardiac arrest pathway. Crit Pathw Cardiol 2013;12:28–30. PMID: 23411605.

54. Wong SC, Sleeper LA, Monrad ES, et al. Absence of gender differences in clinical outcomes in patients with cardiogenic shock complicating acute myocardial infarction: a report from the SHOCK trial registry. J Am Coll Cardiol 2001;38:1395–401. PMID: 11691514.

55. Hochman JS, Tamis JE, Thompson TD, et al. Sex, clinical presentation, and outcome in patients with acute coronary syndromes. N Eng J Med 1999;341:226–32. PMID: 10413734.

56. van der Heijden AC, Borleffs CJ, et al. Gender-specific differences in clinical outcome of primary prevention implantable cardioverter defibrillator recipients. Heart. 2013;99:1244–9. PMID: 23723448.

57. Peberdy MA, Kaye W, Ornato JP, et al. Cardiopulmonary resuscitation of adults in the hospital: a report of 14 720 cardiac arrests from the National Registry of Cardiopulmonary Resuscitation. Resuscitation 2003;58:297–308. PMID: 12969608.

58. Sedgwick P, Greenwood N. Understanding the Hawthorne effect. BMJ 2015;351:h4672. PMID: 26341898.