Research

CPR quality among paramedics and ambulance officers: a cross-sectional simulation study

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Abstract

Introduction

High quality cardiopulmonary resuscitation (CPR) improves survival from cardiac arrest, yet CPR quality is often suboptimal, even among trained rescuers. St John Western Australia sought to gather anonymous baseline data on CPR performance by paramedics and ambulance officers in a simulation setting.

Methods

In a cross-sectional study, participants performed 2 minutes of CPR on a manikin. CPR quality was recorded and compared to recommended standards. Comparisons were also made between women and men.

Results

The final cohort comprised 1320 participants; 56% paramedics, 20% transport officers and 18% volunteer emergency medical technicians and emergency medical assistants. More than half achieved an overall score of 90% or greater. The median compression score was 96% (IQR 83–99%) while the median ventilation score was 94% (76–99%). Participants achieved the recommended chest compression fraction of $\geq 60\%$ in 98% of cases. More than half of participants had 99% or more of their compressions reach a depth of ≥ 50 mm. Two-thirds (68%) recorded a mean compression rate in the range 100–120 compressions per minute. Although there were significant differences in the percentage of compressions deep enough ($p < 0.01$) and the 2-minute mean compression depth ($p < 0.01$) between men and women, the effect size was small. However, men were less likely than women to fully release pressure on the chest after compressions ($p < 0.01$).

Conclusion

This study provides useful baseline data about CPR quality in a manikin model. Participants achieved relatively high scores for most CPR quality metrics and complied with CPR guidelines in the majority of cases.

Keywords:

cardiopulmonary resuscitation; cardiac arrest; paramedic; ambulances; CPR quality

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Introduction

Survival from out-of-hospital cardiac arrest (OHCA) is dependent on a number of time-critical interventions. These are summarised in the chain of survival, which is comprised of four links: early recognition of those at risk of cardiac arrest and early call for help from emergency medical services; early cardiopulmonary resuscitation (CPR); early defibrillation; and the implementation of effective post-resuscitation care (1,2). The provision of bystander CPR and public access defibrillation has been shown to contribute towards survival (3-8). Likewise the provision of 'good quality' CPR, in particular compressions that are of an adequate depth, delivered at an adequate rate, has been linked to improved survival outcomes (9-14). Other components of 'good quality' CPR include the minimisation of interruptions to CPR, (15-18) the minimisation of leaning on the chest between compressions and the delivery of effective ventilations (9,19-21). However, CPR quality has been frequently demonstrated to be suboptimal, even among trained rescuers and healthcare professionals (22-24).

St John Western Australia (SJWA) is a provider of ambulance and healthcare services in the state of Western Australia, and strives to improve outcomes for OHCA patients (25). SJWA sought to collect baseline data on CPR skill performance by its paramedics, transport officers, volunteer emergency medical technicians (EMTs) and emergency medical assistants (EMAs) in a cross-sectional manikin study.

Methods

Study design

SJWA clinical services staff attended SJWA regional seminars and continuing education programs (CEPs) between April 2018 and March 2019, and invited clinical staff and volunteers including paramedics, transport officers and volunteer EMTs and EMAs to perform 2 minutes of CPR on a Laerdal manikin fitted with CPR quality measurement technology (SimPad SkillReporter) (26). A 2-minute time interval was chosen because this is the default setting on the Laerdal apparatus and because SJWA Clinical Practice Guidelines require CPR providers to swap every 2 minutes in order to reduce fatigue (27). Participation in the study was voluntary and no personal identifiers were collected. Participants were advised that the summary statistics about their CPR performance would be analysed for the purpose of improving CPR quality. Following 2 minutes of CPR, participants were provided with feedback about their CPR performance and advised as to how it might be improved (participants did not have access to continuous feedback while performing CPR). There was no punitive action for poor performance. The Prehospital, Resuscitation and Emergency Care Research Unit (PRECRU) at Curtin University was asked to analyse the (anonymous) summary data that was collected.

Setting

SJWA is the primary provider of emergency ambulance services in Western Australia, a state with a population of 2.6 million and a land area of 2.5 million square kilometres (28). The capital city, Perth, (with a population of approximately 2 million) is serviced by qualified paramedics. The state's larger regional areas are serviced by qualified paramedic crews or mixed crews consisting of qualified paramedics and volunteer EMTs/EMAs, while smaller regional areas are serviced by volunteer EMTs/EMAs only (29). Paramedics are generally qualified by completing a 4-year undergraduate university course together with on-road training and development components. EMAs and EMTs are volunteer ambulance officers with a basic life support scope of practice, who are trained by SJWA in-house within a governed educational structure. EMA is the first clinical level; officers can progress to the subsequent level of EMT dependent on experience and the completion of additional training. Transport officers, also with a BLS scope of practice, complete a 3-week SJWA internal training course, within a governed educational structure, and are employed in the non-urgent transport of patients. Some transport officers also volunteer as EMAs or EMTs to partake in frontline emergency response. All paramedics, EMAs, EMTs and transport officers are required to complete CEPs every year. SJWA attend approximately 2500 OHCA cases annually, with resuscitation attempted by paramedics, EMTs, EMAs or transport officers in around 1200 cases (25).

Data collection

For each participant, data were collected on the following CPR quality metrics that are routinely measured by the SimPad SkillReporter: overall score (a summary CPR quality score that is calculated based on other CPR quality metrics using Laerdal's proprietary algorithm), compression score, ventilation score, chest compression (flow) fraction, percentage of compressions deep enough, percentage of compressions with adequate rate, mean compression rate (subsequently referred to as the '2-minute mean compression rate'), percentage of compressions fully released, percentage of compressions with correct hand position, mean ventilation rate and the percentage of ventilations with adequate volume (30). For a subset of the data (approximately half of cases) mean compression depth (subsequently referred to as the '2-minute mean compression depth') was also measured. Participants' gender and role at SJWA (highest clinical level achieved) were also recorded. In addition, the setting from which data was collected (eg. a regional seminar or CEP) was recorded for each participant.

Data analysis

PRECRU was provided with an Excel spreadsheet by SJWA containing the above CPR quality metrics and demographic data. This was imported into IBM SPSS version 26 and the data were scrutinised for typographical errors/impossible mathematical values (eg. percentages exceeding 100%) and duplication errors in data recording.

Subsequently, descriptive statistics were derived for each of the CPR quality metrics. Median and interquartile range (IQR) were reported given the non-normally distributed data. CPR performance was compared to three sets of international guideline recommendations (Table 1); SJWA operates under the guidelines issued by the Australian and New Zealand Committee on Resuscitation (ANZCOR) (31), however comparisons were also made to guidelines issued by the American Heart Association (AHA) and the European Resuscitation Council (ERC) (19,20). We also compared performance between men and women, as well as between paramedics and non-paramedics. For statistical comparisons we used either a

chi-squared test for comparing proportions or a Mann-Whitney U-test for comparing non-normally distributed data. We employed a significance level of $\alpha=0.05$. We also constructed box and whisker plots to visually describe and compare distributions.

Ethics approval

Ethics approval for the evaluation of the SJWA data by PRECRU was obtained from the Curtin University Human Research Ethics Committee (HRE2018-0676).

Table 1. Recommended values for compression depth, compression rate and chest compression (flow) fraction, as per three sets of CPR guidelines

CPR quality metric	Guidelines		
	ANZCOR guidelines (31)	AHA guidelines (19)	ERC guidelines (20)
Compression depth	≥ 50 mm	50-60 mm	50-60 mm
Compression rate	100-120 cpm	100-120 cpm	100-120 cpm
Chest compression flow fraction	Minimise interruptions	Minimise interruptions; $\geq 60\%$	Minimise interruptions

Figure 1. Selection of cases to be included in analysis

*Two cases had only 17 compressions recorded each and were therefore excluded from analysis. All other cases had a minimum of 60 compressions (equivalent to at least two rounds of 30:2 CPR).

Results

From 1373 records that were collected, 49 were found to be duplicates, two had no CPR quality data recorded and two cases had insufficient data captured (only 17 compressions per case). This resulted in a total of 1320 records in the final dataset that were analysed (Figure 1).

The data originated from across 18 settings in Western Australia. The largest proportion of cases was derived from the paramedic CEP (n=622; 47.1%). The second largest contribution was from the transport officers' CEP (n=261; 19.8%). Contributions from the remaining settings were minor, ranging from 0.5% to 4.2% of the cohort. Accordingly, over half the cohort (55.6%) was comprised of paramedics, while 19.7% represented patient transport officers and 17.8% represented volunteer EMTs and EMAs. Students, cadets and those who fell into the category of 'other' comprised the remaining 6.9% of the cohort. Of those who provided a response, 55% were male and 45% were female.

CPR performance metrics

The median overall score was 91% (IQR 75–97%). The median compression score was 96% (IQR 83–99%) while the median ventilation score was 94% (IQR 76–99%) (Figure 2). Participants had a median chest compression flow fraction of 72% (IQR 69–74%) (Figure 2). For 98% of participants, the compression flow fraction was 60% or greater, in compliance with AHA recommendations (Table 1) (19).

The median percentage of compressions that were deep enough was 99% (IQR 76–100%) (Figure 2). Where the 2-minute mean compression depth had been recorded (in approximately half of the cohort (n=696; 53%), the median value among participants was 57 mm (IQR 53–61 mm) (Figure 3). The majority of these participants (88.6%) achieved or exceeded the minimum 50 mm depth recommended by Australian and international guidelines (19,20,31), while almost two-thirds (63.2%) recorded a 2-minute mean depth in the range of 50–60 mm, as recommended by the AHA and the ERC (19,20) but not by ANZCOR (31) (Table 1). The median percentage of compressions with adequate rate was 80% (IQR 36–97%) (Figure 2); adequate rate was defined as falling within in the range 100–120 compressions per minute (cpm) (19,20,31). A 2-minute mean compression rate was also recorded for each participant. The median of the 2-minute mean compression rate was 113 cpm across all participants (IQR 106–120 cpm) (Figure 4). Approximately two-thirds of participants (68%) had a 2-minute mean compression rate within the range 100–120 cpm. Just under a quarter (23%) recorded a 2-minute mean compression rate above the upper recommended value of 120 cpm, while 9.5% had a 2-minute mean compression rate below 100 cpm. The median percentage of compressions that were fully released was 94% (IQR 59–99%) (Figure 2). Overall 84% of participants used the correct hand position on the central chest for every compression delivered (Figure 2). A median

of nine ventilations (IQR 6–10 ventilations) were delivered during the simulated CPR. The median ventilation rate was five ventilations per minute (vpm) (IQR 4–5 vpm), while the median percentage of ventilations with adequate volume was 75% (IQR 43–92%) (Figure 2).

CPR performance by men and women

Table 1 and Figure 5a compare CPR performance between men and women. There was a significant difference in overall scores between men (median 93%, IQR 80–97%) and women (89%, 74–96%) ($p<0.01$). There was also a significant difference in ventilation scores between men (96%, 86–99%) and women (90%, 50–99%) ($p<0.01$). There was however no significant difference in compression scores ($p=0.53$). Both men and women recorded a median chest compression flow fraction of 72%, and similar interquartile ranges (70–75% for men; 68–74% for women). Despite these similarities, there was a significant difference between men and women in the ranking of compression fraction values ($p<0.01$).

The percentage of compressions that were deep enough differed significantly between men and women ($p<0.01$). Although their median percentages were similar (99% for men; 98% for women), the difference between their distributions was evident in the large difference in the 25th percentiles (90% for men; 49% for women). There was also a significant difference in the 2-minute mean compression depths observed among men (median 58 mm, IQR 54–61 mm) and women (56 mm, 52–60 mm) ($p<0.01$) (within the subset of cases where this data had been recorded [N=696]). There was no significant difference in the percentage of compressions with adequate rate (median 78%, IQR 33–98% for men; 85%, 43–97% for women; $p=0.19$), nor in the 2-minute mean compression rate (median 114 cpm, IQR 107–120 cpm for men; 112cpm, 106–119 cpm for women; $p=0.14$). However, men exhibited more leaning on the chest during CPR, as evidenced by the significant difference in the percentage of compressions fully released (median 89%, IQR 37–99% for men; 97%, 78–100% for women; $p<0.01$). There were also significant differences by gender in the ventilation rate (median 5 vpm, IQR 4–5 vpm for men; 4 vpm, 3–5 vpm for women; $p<0.01$) and the percentage of ventilations with adequate volume (median 80%, IQR 50–100% for men; 67%, 40–90% for women; $p<0.01$). More men were paramedics than women (67.2% vs. 43.9%; $p<0.01$).

CPR performance by paramedics and non-paramedics

There was a significant difference between paramedics and non-paramedics with regards to the majority of CPR quality metrics, with the exception of 2-minute mean compression depth ($p=0.76$) and 2-minute mean compression rate ($p=0.73$) (Table 1 and Figure 5b). In general paramedics tended to achieve higher CPR quality scores compared to non-paramedics, as evidenced by their higher median overall score (93% compared to 88%), compression score (97% compared to 94%) and ventilation score (97% compared to 90%).

Figure 2. Box plots describing the CPR performance of the study cohort

Boxes represent the IQR (1st to 3rd quartile). The bold vertical line represents the median. The whiskers extend to the highest and lowest values which are no greater than 1.5 x IQR from the median. The circles represent outliers which are between 1.5 x IQR – 3 x IQR from the median. The stars represent extreme outliers which are more than 3 x IQR from the median.

Note: Given that ventilations were delivered during the simulation exercise, a chest compression flow fraction of <100% would be expected; 84% of the cohort achieved 100% for this metric.

Figure 3. Frequency distribution for the 2-minute mean compression depth (mm) in half the cohort where this data was collected (n=696; 53%)

Figure 4. Frequency distribution for the 2-minute mean compression rate for the cohort (n=1297)

Figure 5a. Box plots describing CPR performance for men versus women

*Indicates significant difference.

Boxes represent the interquartile range (IQR) (1st to 3rd quartile). The bold vertical line represents the median. The whiskers extend to the highest and lowest values which are no greater than 1.5 x IQR from the median. The circles represent outliers which are between 1.5 x IQR – 3 x IQR from the median. The stars represent extreme outliers which are more than 3 x IQR from the median.

Table 2. CPR performance for men vs. women and paramedics vs. non-paramedics

	Male ¹	Female ¹	p-value	Paramedic ¹	Non-paramedic ¹	p-value
N	698 ²	570 ²		734	586	
Male (%)				63.9 ²	39.1 ²	<0.01 ³
Paramedic (%)	67.2	43.9	<0.01 ³			
Overall score (%)	93 (80-97)	89 (74-96)	<0.01 ⁴	93 (82-98)	88 (71-96)	<0.01 ⁴
Compression score (%)	96 (85-98)	96 (81-99)	0.53 ⁴	97 (88-99)	94 (76-98)	<0.01 ⁴
Ventilation score (%)	96 (86-99)	90 (50-99)	<0.01 ⁴	97 (83-99)	90 (63-98)	<0.01 ⁴
Compression flow fraction (%)	72 (70-75)	72 (68-74)	<0.01 ⁴	72 (69-75)	71 (68-74)	<0.01 ⁴
Percentage of compressions deep enough (%)	99 (90-100)	98 (49-100)	<0.01 ⁴	99 (83-100)	98.5 (56-100)	<0.01 ⁴
2-minute mean compression depth (mm) ⁵	58 (54-61)	56 (52-60)	<0.01 ⁴	57 (53-60)	58 (53-61)	0.76 ⁴
Percentage of compressions with adequate rate (%)	78 (33-98)	85 (43-97)	0.19 ⁴	82 (40-98)	78.5 (27-97)	0.045 ⁴
2-minute mean compression rate (cpm)	114 (107-120)	112 (106-119)	0.14 ⁴	113 (107-120)	113 (106-120)	0.73 ⁴
Percentage of compressions fully released (%)	89 (37-99)	97 (78-100)	<0.01 ⁴	96 (65-100)	90 (54-99)	<0.01 ⁴
Percentage of compressions with correct hand position (%)	100 (100-100)	100 (100-100)	0.08 ⁴	100 (100-100)	100 (100-100)	<0.01 ⁴
Mean ventilation rate (vpm)	5 (4-5)	4 (3-5)	<0.01 ⁴	5 (4-5)	4 (3-5)	<0.01 ⁴
Percentage of compressions with adequate volume	80 (50-100)	67 (40-90)	<0.01 ⁴	80 (50-100)	67 (33-90)	<0.01 ⁴

Note: 1) Results are reported as counts, proportions or median (IQR) as appropriate; 2) N=52 participants did not specify gender; 3) p-value derived using chi-squared test; 4) p-value derived using Mann-Whitney U-test; 5) Mean compression depth was measured in approximately half of the cohort (n=696; 53%)

Discussion

In this cross-sectional study, CPR quality was measured in a simulation (manikin-based) setting across 1320 SJWA staff and clinical volunteers. More than half of participants achieved an overall score of more than 90%. The overall score is calculated from the compression score, ventilation score and chest compression flow fraction using Laerdal's proprietary algorithm. The algorithm assigns a score of 100% where there is perfect compliance with CPR guidelines (19,20,31) while reducing the score for guideline deviations (the larger the deviation, the more the score is reduced) (30). Half of participants attained a compression score of 96% or greater, while half attained a ventilation score of 94% or greater. The median compression flow fraction was 72% (IQR 69–74%). Because most participants delivered ventilations, a compression flow fraction close to 100% would not be expected. However, almost all participants (98%) had a compression flow fraction of 60% or greater, reaching or exceeding the minimum value recommended by AHA guidelines (19).

More than half of participants had 99% or more of their compressions considered 'deep enough' (defined as achieving a compression depth of 50 mm or greater) (19,20,31). This is important because deeper compressions have been linked to improved patient survival outcomes (9–11,13,14). Similarly, in half the cohort (53%) where the 2-minute mean compression depth had been recorded, the vast majority of participants (88.6%) achieved a mean depth of at least 50 mm. Although some participants recorded a 2-minute mean compression depth greater than the 60 mm maximum value recommended by the AHA and the ERC (19,20), the guidelines issued by ANZCOR (under which SJWA operate) do not advise an upper limit on compression depth (31).

All three guidelines used as a reference in this study recommend maintaining a compression rate in the range of 100–120 cpm (19,20,31) because compression rates in this range have been linked to improved patient survival (9). In the study cohort, half of participants had 80% or more of their compressions within this recommended range. While the median 2-minute

Figure 5b. Box plots describing CPR performance for paramedics versus non-paramedics

*Indicates significant difference.

Boxes represent the interquartile range (IQR) (1st to 3rd quartile). The bold vertical line represents the median. The whiskers extend to the highest and lowest values which are no greater than 1.5 x IQR from the median. The circles represent outliers which are between 1.5 x IQR – 3 x IQR from the median. The stars represent extreme outliers which are more than 3 x IQR from the median.

mean compression rate for the cohort was 113 cpm (IQR 106–120cpm), almost a quarter (23%) of participants recorded a 2-minute mean compression rate that was 'too fast' (above 120 cpm). In the literature, excessive compression rates have been linked to lower compression depths over time (14). These findings highlight compression rate as a potential area of focus for education and training providers.

During the 2 minutes of simulated CPR in this manikin study, a median of nine ventilations (IQR 6–10 ventilations) were delivered by participants. However, in 7% of cases no ventilations were recorded. Feedback from SJWA clinical investigators indicated that some participants had struggled with the set-up of the study and that the positioning of the bag valve mask relative to the manikin in some cases reflected poor ventilations. There was a vast degree of variability in the percentage of ventilations with adequate volume, as reflected by the large interquartile range (median 75%, IQR 43–92%). There were also significant differences between men and women in terms of their ability to achieve adequate ventilation volume ($p<0.01$); women generally appeared to have more difficulty in achieving adequate volume compared to men. We suggest that this may have been due to greater difficulty in achieving an adequate seal between the bag valve mask and the manikin's face, while maintaining an appropriate head tilt. Nevertheless, almost a quarter of participants who delivered ventilations recorded adequate volume for each ventilation.

In comparisons of CPR quality between men and women, overall score was found to differ significantly by gender ($p<0.01$). Men attained a higher median overall score compared to women (93% compared to 89%). Given that the overall score is calculated based on the compression score, the ventilation score and the chest compression flow fraction, this finding in men appears to be primarily driven by the higher ventilation scores observed among men (median 96% for men compared to 90% for women; the distributions were significantly different for men and women; $p<0.01$). Compression scores did not differ significantly by gender ($p=0.53$). Although both men and women achieved an identical value for the median compression flow fraction (72%) and similar interquartile ranges recorded for men and women (70–75% vs. 68–74%), the distribution of compression flow fractions for men and women were statistically significantly different ($p<0.01$). This partly reflects the sensitivity of the statistical test (Mann Whitney U-test) to detect changes across the full distribution of values (ie. including the tails of the distributions). Given the high degree of similarity in median and interquartile range, we propose that any difference between men and women in compression flow fraction is confined to a small proportion of participants and therefore of limited clinical significance.

The percentage of compressions that were deep enough differed significantly between men and women ($p<0.01$). While men and women both recorded a high median value (99% and 98% respectively), three-quarters of men scored 90% or more,

while three-quarters of women scored 49% or more. There was likewise a significant difference in 2-minute mean compression depth between men and women ($p<0.01$), where this data had been collected (in approximately half the cohort). Although lower compression depths among women have previously been reported in the literature (32), the median values observed for both men and women in our cohort (58 mm and 56 mm respectively) were still notably greater than the minimum depth of 50 mm recommended by all three CPR guidelines used as a reference in this study (19,20,31).

Neither the percentage of compressions with adequate rate nor the 2-minute mean compression rate differed significantly by gender ($p=0.19$ and $p=0.14$ respectively). However, there was a significant difference between men and women in terms of the amount of leaning on the chest during CPR ($p<0.01$). Women tended to demonstrate less leaning than men; the median percentage of compressions fully released was 97% among women compared to 89% among men. The more frequent occurrence of leaning among men indicates another potential area of focus for education and training providers.

A significantly higher proportion of men were paramedics compared to women (67.2% vs. 43.9%; $p<0.01$), which may have influenced the recorded CPR performance for each group. In our comparison of CPR quality between paramedics and non-paramedics, paramedics scored statistically significantly higher on almost all CPR quality metrics. It would be reasonable to expect this finding given the exposure to OHCA (33) and continuing education opportunities.

To encourage optimisation of CPR performance, in 2018 SJWA introduced a CPR quality improvement initiative called IMPACT (IMproved Performance And CPR Team) (25). This approach focuses on a 'pit crew' style of CPR delivery that aims to provide highly quality focussed compressions with minimal interruptions. Other components of this initiative include standardised equipment placement, the use CPR quality monitoring devices with real-time feedback and the mandatory swapping of rescuers every 2 minutes. SJWA continues to monitor the effectiveness of such interventions.

Study strengths and limitations

This study has a number of strengths. It has a large sample size ($N=1320$), with data collected from across SJWA operations, including from qualified paramedics, patient transport officers, volunteer EMTs and others. Additionally, data was collected in a standardised manner using Laerdal CPR quality measurement technology, which is routinely used by SJWA and widely used by other ambulance services (therefore allowing for either temporal or cross-service comparisons of CPR performance).

This study has several limitations. First, CPR quality data was collected voluntarily in a simulation setting and therefore may

not accurately reflect the quality of CPR that would occur in clinical practice. Second, we did not have access to Laerdal's proprietary algorithm that was used to calculate the compression score, ventilation score and overall score, so where there appeared to be a mismatch between these scores and the other CPR quality metrics we could not undertake calculations to check the validity of these data points. In approximately one in 10 cases no ventilations were delivered. SJWA reported some methodological difficulties with the equipment set-up that may have led to poorer quality ventilations than expected; this may have led to an overall poorer performance being recorded than may have otherwise existed. Finally, this was an initial analysis that did not adjust for potential confounders when comparing CPR performance by gender or by qualification (paramedic vs. non-paramedic); future work could include adjustment for confounders through the construction of relevant regression models.

Conclusion

This study provides useful baseline data about CPR quality among SJWA paramedics, transport officers, EMTs and EMAs in a simulation setting. Participants achieved relatively high scores on most CPR quality metrics and complied with CPR guidelines in the majority of cases. Further training should focus on maintaining compression rates in the range of 100–120 cpm, in particular avoiding compression rates that are too fast, minimising the occurrence of leaning among male rescuers, and recognising that women may have more difficulty in maintaining adequate compression depth compared to men.

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Competing interests

The authors declare no competing interests. Each author of this paper has completed the ICMJE conflict of interest statement. Authors DR, PB, DB, KS, MD and LD are SJWA employees. Authors SB and JF hold adjunct research positions with SJWA, and PRECRU received research funding from SJWA. None of the authors are affiliated with Laerdal.

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