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Cardiopulmonary Resuscitation in the Prone Position in the Operating Room or in the Intensive Care Unit: A Systematic Review

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The prone position is commonly used in certain surgical procedures and to improve oxygenation in mechanically ventilated patients with acute respiratory distress syndrome (ARDS). Cardiorespiratory arrest (CRA) in this position may be more challenging to treat because care providers trained in conventional cardiopulmonary resuscitation (CPR) may not be familiar with CPR in the prone position. The aim of this systematic review is to provide an overview of current evidence regarding the methodology, efficacy, and experience of CPR in the prone position, in patients with the airway already secured. The search strategy included PubMed, Scopus, and Google Scholar. All studies published up to April 2020 including CRA or CPR in the prone position were included. Of the 268 articles located, 52 articles were included: 5 review articles, 8 clinical guidelines in which prone CPR was mentioned, 4 originals, 27 case reports, and 8 editorials or correspondences. Data from reviewed clinical studies confirm that CPR in the prone position is a reasonable alternative to supine CPR when the latter cannot be immediately implemented, and the airway is already secured. Defibrillation in the prone position is also possible. Familiarizing clinicians with CPR and defibrillation in the prone position may improve CPR performance in the prone position. (Anesth Analg 2021;132:285–92)

GLOSSARY

AHA = American Heart Association; **ARDS** = acute respiratory distress syndrome; **BP** = blood pressure; **COVID-19** = coronavirus disease 2019; **CPR** = cardiopulmonary resuscitation; **CRA** = cardiorespiratory arrest; **CT** = computerized tomography; **F** = female; **ICU** = intensive care unit; **IQR** = interquartile range; **M** = male; **NS** = not specified; **P** = prone position; **PRISMA** = Preferred Reporting Items for Systematic Reviews and Meta-Analyses; **PROSPERO** = International Prospective Register of Systematic Reviews; **ROSC** = return of spontaneous circulation; **S** = supine position

The prone position is usually used in the operating room to facilitate surgical access and to optimize oxygenation in patients with severe hypoxic respiratory failure in the intensive care unit (ICU). However, if the patient suffers cardiorespiratory

arrest (CRA) in this position, considerable effort is often required to return the patient to the supine position and initiate cardiopulmonary resuscitation (CPR) maneuvers. It can take as many as 5–6 people and up to 3 minutes to reposition a patient into the supine position.¹

Patients testing positive for coronavirus disease 2019 (COVID-19) may require ICU admission for persistent refractory hypoxemia. For such patients, mechanical ventilation in the prone position may improve oxygenation.²

However, if patients who are mechanically ventilated in the prone position suffer cardiac arrest, it is not clear how CPR should be performed. The American Heart Association (AHA) 2010 guideline prioritizes placing the patient in the supine position to perform optimal CPR. Performing CPR in the prone position is only recommended when it is not possible to turn the patient supine. However, the recommended technique to perform prone CPR is not specified, and prone CPR is mentioned in neither the 2015 nor the 2019 updates.^{3–5} A 2020 update of basic and advanced CPR recommendations for the COVID-19 pandemic⁶ recommends either returning the patient to the supine

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position or initiating CPR in the prone position. How CPR should be performed, however, is not specified.^{6,7} Because patients with COVID-19 often have severe cardiorespiratory instability, a rapid change of position might lead to greater hemodynamic instability and worsened hypoxemia. CPR in such patients may be better managed in the prone position.

We performed a systematic review of current literature regarding the efficacy and feasibility of basic or advanced CPR maneuvers in the prone position in the operating room or in the ICU. As a secondary objective, we offer a description of recommendations for basic and advanced CPR in the prone position to facilitate its application in patients undergoing CRA in this position.

METHODS

Eligibility Criteria

Studies published up to April 2020 concerning CRA or CPR in the prone position were eligible for this systematic review. We included articles containing data on patients who had undergone prone CRA and received prone CPR, as well as those studying the efficacy or methodology of prone CPR. Those articles reporting cases in which CRA occurred in the prone position but CPR was performed after turning patients supine were excluded. This systematic review was conducted in accordance with current guidelines on systematic literature reviews and registered at the International Prospective Register of Systematic Reviews (PROSPERO) (CRD42020197458). This article adheres to the applicable Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Search Strategy

Studies were identified within the electronic databases PubMed, Scopus, and Google Scholar. Search strategy performed was as follows:

In PubMed: ((“PronePosition”[Mesh])OR(prone[tiab]) AND (“Cardiopulmonary Resuscitation”[Mesh]) OR (“Cardiopulmonary Resuscitation”[ti]) OR (CPR[ti]) OR (“Cardio Pulmonary Resuscitation”[ti]) OR (“Basic Cardiac Life Support”[ti]) OR (“Advanced Cardiac Life Support”[ti]) OR (“Heart Arrest”[Mesh]) OR (“Cardiac Arrest”[ti]) OR (“Cardiopulmonary Arrest”[ti]) OR (“Heart Arrest”[ti]) OR (“basic life support”[tiab])).

In Scopus: (TITLE-ABS-KEY(((proneAND(posit*OR postur*)) AND TITLE-ABS-KEY (“Cardiopulmonary Resuscitation” OR cpr OR “Cardio Pulmonary Resuscitation” OR “Basic Cardiac Life Support” OR “Advanced Cardiac Life Support” OR “Heart Arrest” OR “Cardiac Arrest” OR “Cardiopulmonary Arrest” OR “basic life support”))).

In Google Scholar: (prone AND (posit* OR postur*)) AND (“Cardiopulmonary Resuscitation” OR

cpr OR “Cardiac Life Support” OR “Heart Arrest” OR “Cardiac Arrest” OR “Cardiopulmonary Arrest” OR “basic life support”).

Study Selection

Titles and abstracts of articles retrieved by the search were screened for relevance. Selection of articles was performed by 2 authors using predefined screening criteria and who screened all titles and abstracts obtained from the systematic search independently. Any disagreements regarding inclusion were resolved via discussion between the 2 review authors. A third author was consulted if an agreement could not be reached.

All studies published up to April 2020 and with the full text available in English, Spanish, Portuguese, or French were eligible. No type of document restriction was applied, and no methodology filters were used.

The reasons for excluding studies included duplicated articles, publications in which patients had not presented CRA, did not require CPR or CPR was performed in supine position, publications referring to sudden infant death, and those written in languages other than those in the inclusion criteria. A flowchart illustrating the process of study selection is presented in Figure 1.

Data Extraction

Using a predefined data extraction form, data were gathered from individual articles (type of study, information provided in each article). Any discrepancies in the extracted data were resolved via discussion between authors.

Data obtained from observational studies were summarized in a formal narrative synthesis. Information obtained from case reports was compared and summarized. Data regarding the recovery time of spontaneous circulation were summarized numerically, as median (interquartile range [IQR]). Because no randomized clinical trials were identified, data extraction was based on conclusions found in reviews, methods, and results inferred from observational studies and results reported in case reports.

RESULTS

Our search returned a total of 268 articles: 78 on PubMed, 177 on Scopus, and an additional 13 on Google Scholar. After removing duplicate articles, 199 remained. Of these, 92 were excluded for not meeting the inclusion criteria. Full text could not be obtained for 55 articles, leaving 52 articles for review and inclusion. Reasons for exclusion were as follows: 40 articles did not address prone CPR; 15 articles focused on sudden infant death attributed to sleeping in the prone position; 9 articles did not describe prone CRA; 7 articles described aspects of acute respiratory

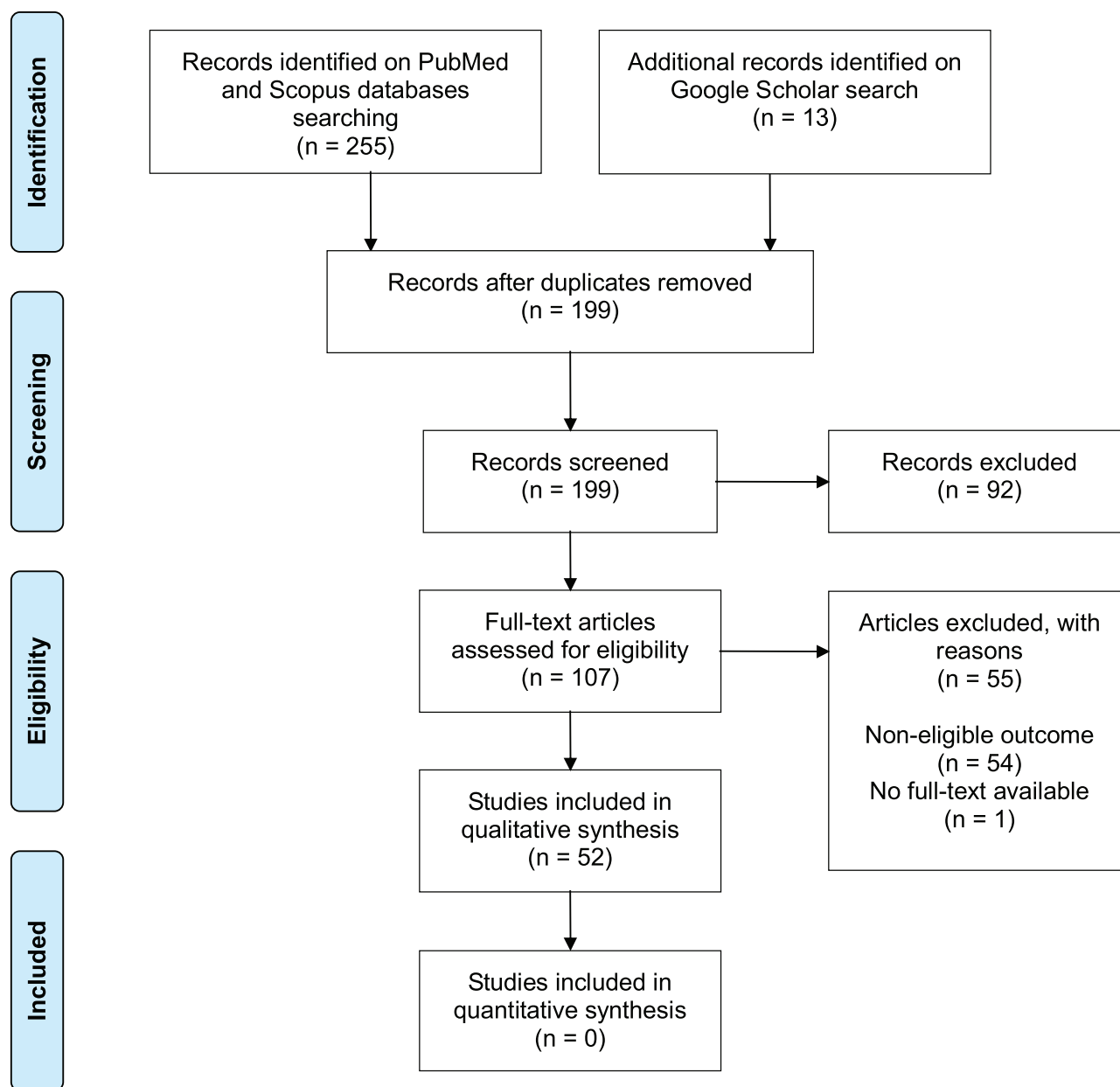


Figure 1. PRISMA flow diagram. PRISMA indicates Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

distress syndrome (ARDS) without mentioning CRA or CPR; 5 articles examined CRA situations in which CPR could not be performed; 2 articles involved patients during surgery in the prone position who underwent CPR in the supine position; 3 articles involved sudden death in the prone position involving patients detained by the police; 2 articles using the term “prone to” as to mean “tendency to”; and 9 articles written in languages other than those selected in the inclusion criteria.

Abstracts of the 55 articles from which the full text could not be retrieved were then reviewed. Fifty-four did not meet inclusion criteria (39 articles did not address prone CPR, 5 articles on ARDS did not

mention prone CRA or CPR, 1 article studied sudden infant death attributed to sleeping in prone position, 3 articles using the term “prone to” as a translation of “tendency to,” and 6 articles were written in a language different from those selected). From the remaining article, which met initial inclusion criteria, full text was not accessible.⁸

Fifty-two full-text documents fulfilling our inclusion-exclusion criteria remained for review: 4 reviews on CPR in the prone position; 1 review on CPR in positions other than supine; 8 clinical practice guidelines; 4 original articles (observational experimental studies); 27 articles describing 32 case reports on prone CPR; and 8 comments, editorials, or correspondence.

Table 1. Cases Reported of CRA in Prone Position

CRA position	CPR position	Defibrillation	ROSC
Prone (n = 32)	Prone (n = 14)	Yes (n = 3)	Yes (n = 3)
		No (n = 11)	Yes (n = 11)
	Supine (n = 11)	No (n = 11)	Yes (n = 6)
			No (n = 5)
	Prone start then turned into supine (n = 3)	Right side (n = 1)	Yes (n = 1)
	Supine (n = 2)	Supine (n = 1)	Yes (n = 1)
		Thoracotomy (n = 1)	No (n = 1)
	Thoracotomy and direct cardiac massage (n = 1)	Yes (n = 1)	Yes (n = 1)
	Not mentioned (n = 3)	Yes (n = 1)	Yes (n = 1)
		No (n = 1)	No (n = 1)
		Not mentioned (n = 1)	Not mentioned (n = 1)

Abbreviations: CPR, cardiopulmonary resuscitation; CRA, cardiorespiratory arrest; ROSC, return of spontaneous circulation.

Observational Experimental Studies

Four original articles addressing prone CPR were reviewed: 2 studies were performed in patients or volunteers.^{9,10} A third study involved simulation,¹¹ and the fourth reviewed computerized tomography (CT) images to locate the best area to perform chest compressions in the prone position.¹²

Two studies compared hemodynamic parameters obtained during resuscitation in the prone position with those obtained while supine. Both studies targeted patients who had already received standard supine CPR. In a 2003 study, 6 patients who had already undergone supine CPR for 30 minutes without return of spontaneous circulation (ROSC) received an additional 15 minutes of supine CPR followed by 15 minutes of prone CPR. Mean and systolic blood pressures (BPs) were higher in the prone position.⁹ In a similar 2006 study, 11 patients who had expired in the ICU underwent 1 minute of supine CPR followed by 1 minute in the prone position. The systolic BP generated was 79.4 ± 20.3 mm Hg in prone versus 55.4 ± 20.3 mm Hg in supine; diastolic BP generated was 16.7 ± 10.3 mm Hg in prone versus 13.0 ± 6.7 mm Hg in supine. This study also found that prone compressions alone in healthy volunteers generated a mean tidal volume of 399 ± 110 mL or approximately 6 mL/kg, the recommended tidal volume in lung-protective ventilation.¹⁰

A 2000 simulation study evaluated the efficacy of chest compressions delivered by nurses to a manikin in prone position during an accredited CPR course. Nurses delivered 100 compressions with a support placed under the sternum. The study found that 41% of nurses could deliver adequate CPR for all 100 compressions, 61% of nurses were able to deliver adequate CPR during some compressions, and 40.6% were partially effective.¹¹

A 2017 study reviewed CT thoracic images to locate the optimal hand position for compressions performed in the prone position and concluded that T7–T9 was the most effective location because it aligned with the place where cardiac section is the widest.¹²

Case Reports

The majority of published data on prone CPR were in case report form. Twenty-seven articles reporting 32 cases of possible CPR in prone position were initially identified (Table 1): in 29 of these cases, CPR was performed as a result of CRA during surgery in the prone position, 2 patients underwent prone CPR during the performance of a CT-guided biopsy, and 1 during ventilation in the prone position due to respiratory distress. Surgical procedures performed in the prone position primarily involved brain tumor resection and spinal surgery. The etiology of CRA was air embolism in 11 cases, hemorrhage in 7 cases, vagal stimulation in 4 cases, heart disease in 3 cases, airway compression in 2 cases, hyperkalemia in 1 case, and unknown in 4 cases.^{13–39}

We excluded 56% (18 of 32) of case reports we initially identified because the CPR position was not mentioned or CPR was not performed in the prone position. CPR was performed in the prone position in the remaining 14 case reports: 7 (50%) reports occurred during brain tumor surgery, 6 (43%) during spinal surgery, and 1 (7%) during mechanical ventilation in prone position. ROSC was achieved in all patients without changing the patient's position to supine. Patient characteristics are described in Table 2 (57% men; mean age: 35 ± 25 years old). Etiology of CRA was hypovolemia in 6 cases (43%),^{13–18} air embolism in 2 cases (14%),^{19,20} vagal syndromes in 2 cases (14%),^{21,22} coronary acute syndrome in 1 case (7%),²³ supraventricular tachycardia in 1 case (7%),²⁴ airway obstruction in 1 case (7%),¹³ and ARDS in another case (7%).²⁵ The median (IQR) time of CPR before ROSC was 5 minutes (3–7 minutes).

DISCUSSION

Performance of basic and advanced CPR in the supine position is well established, and detailed guidelines exist to standardize performance. However, guidance as to CPR in the prone position is less complete. Prone CPR carries potential advantages with respect to speed of initiation, particularly when arrest is witnessed.

Table 2. Demographics and CPR Data of Patients Suffering From CRA and CPR in Prone Position

Reference	Gender	Age	Procedure	Suspected etiology of CRA	CPR position	Defibrillation	ROSC	Duration (min)
Sun et al ¹³	F	14 y	Craniectomy	Hypovolemia	P	No	Yes	5
Sun et al ¹³	M	34 y	Spinal surgery	Endotracheal tube obstruction	P	No	Yes	6
Tobias et al ¹⁴	M	12 y	Spinal surgery	Hypovolemia	P	No	Yes	7
Gueugniaud et al ¹⁵	M	15 y	Spinal surgery	Myocardial ischemia/hypovolemia	P + S	No	Yes	10
Burki et al ¹⁶	F	6 y	Tumor excision	Hypovolemia	P	No	Yes	20
Gomes and Bersot ¹⁷	F	77 y	Tumor excision	Hemorrhagic shock/hypovolemia	P	No	Yes	2
Loewenthal et al ¹⁸	F	53 y	Tumor excision	Hypovolemia	P	No	Yes	3
Brown et al ¹⁹	F	60 y	Spinal surgery	Air embolism	P	Yes	Yes	NS
Kelleher and Mackersie ²⁰	F	16 mo	Craniectomy	Air embolism/Hypovolemia	P	No	Yes	2 episodes: 7 and 4
Chauhan et al ²¹	M	49 y	Lumbar discectomy	Vagal syndrome	P	No	Yes	0.33
Dooney ²²	M	43 y	Lumbar discectomy	Vagal syndrome	P	No	Yes	NS
Taylor et al ²³	M	69 y	Tumor excision	Coronary acute syndrome	P	Yes	Yes	3
Mayorga-Buiza et al ²⁴	M	10 y	Tumor excision	Supraventricular tachycardia	P	Yes	Yes	8
Dequin et al ²⁵	M	48 y	Mechanical ventilation	Acute respiratory distress syndrome	P	No	Yes	5

Abbreviations: CPR, cardiopulmonary resuscitation; CRA, cardiorespiratory arrest; F, female; M, male; NS, not specified; P, prone position; ROSC, return of spontaneous circulation; S, supine position.

Table 3. Criteria That Ideal Basic CPR Maneuvers Should Meet (According to McNeil⁴²)

Not requiring mouth-to-mouth ventilation.
 Not producing gastric distension, relieving stomach pressure and avoiding risk of bronchoaspiration in case of gastric regurgitation.
 No requiring additional maneuvers to keep the airway open.
 Allowing ventilation and circulation to be assisted with the same maneuver. This maneuver should free the upper airway in the same way that a Heimlich maneuver would.
 Being able to be learned in <30 min. Simplicity of the technique should facilitate its memory retention.
 Starting in the initial 4 min after CRA, it allows oxygenation so that advanced CPR can be started within first 8 min, with a high possibility of success.

Abbreviations: CPR, cardiopulmonary resuscitation; CRA, cardiorespiratory arrest.

Speed may be one reason why CPR success in the out-of-hospital setting is lower than in-hospital CRA.⁴⁰ In addition, approximately one-third of patients suffering from in-hospital CRA are already intubated, which also reduces the time needed to initiate chest compressions.⁴⁰ Shortening the time needed to recognize CRA and initiate CPR likely produces better results.

Existing theories regarding the mechanism by which CPR sustains the circulation suggest that prone CPR is feasible. According to the “heart pump” theory, compressions squeeze the heart between the anterior wall of the spine and the sternum, creating a flow in systemic and pulmonary circulations. In contrast, the “chest pump” theory argues that compressions produced in the thorax decrease intrathoracic volume and increase intrathoracic pressure, generating a gradient that produces blood flow to the aorta and the pulmonary arteries.⁹ Both theories are compatible with prone CPR and suggest that the rhythm and the depth of compressions are important aspects of successful CPR. Current data suggest that the cadence of the compressions needs to be adequate to allow backward movement of the chest (100–120 compressions/min).⁴¹

Prone CPR also meets many of criteria originally described by McNeil⁴² in 1989, further underscoring its potential efficacy (Table 3).^{43–47}

For prone CPR, landmarks for hand placement used during supine CPR are obviously ineffective. However, a 2017 imaging study determined that



Figure 2. Location where compressions are recommended to be performed in the prone position. Red line represents location of compressions. Black line represents inferior scapular limit.

hand placement between T7 and T9 locates the compressions over the largest transverse section of the left ventricle (Figure 2).¹²

Existing evidence suggests that prone CPR may generate even better flow than supine CPR. All case

reports included in this review ended with successful ROSC. In addition, in the 2 observational studies of patients who had failed supine CPR, BP values obtained during compressions in the prone position were higher than those obtained in the supine position. Although the mechanisms underlying a possible advantage to prone CPR are unclear, one possibility is that the stiffness of the costovertebral joint allows greater force to be exerted on the heart than compressions performed on the sternocostal joint, which is weaker and more fragile.^{9,42,45} In addition, during sternal compressions in the supine position, diaphragm and abdominal viscera are caudally displaced, and because the anterior abdominal wall is not rigid, part of the applied force is dissipated. During prone CPR, effectiveness of compressions may increase due to the restriction of movement of the abdominal structures if the anterior abdominal wall remains in contact with a firm surface. Likewise, posterior compressions may depress the sternum more efficiently because of the hard surface placed under the sternum, increasing the force delivered to the ventricles (heart pump) and the rapid reduction of intrathoracic volume.^{9,10} One potential downside to prone CPR is that it can be more strenuous than in the supine position due to a stiffer costovertebral joint that requires more pressure to compress. Simulation studies indicating that compressions become more ineffective over time support this possibility.¹¹ CPR in prone position can be more strenuous than in supine position, because force is applied to the dorsal region, which is more rigid than the sternum.¹¹ It is likely that the benefit of training is even higher with prone CPR due to this issue and general unfamiliarity with the procedure.

Some limitations of existing literature deserve mention. Although all patients described in the included case reports achieved ROSC, all patients had a witnessed arrest, a secured airway, monitoring in place, and rapid initiation of CPR.^{13–25,40} In addition, publication

bias is likely given the rarity of prone CPR. It is possible that under real-world conditions, where the airway is unsecured and intravenous access is difficult, the efficacy of prone CPR may decrease. Findings from this review are thus limited to patients, mostly in the operating room, who have sustained an arrest witnessed by an anesthesia provider. Nevertheless, because most opportunities to perform prone CPR likely arise in an intraoperative or ICU context, we believe it reasonable to consider leaving patients prone at least for the first few minutes of CPR.

As with supine CPR, proper performance of prone CPR will increase its potential effectiveness. Compressions should be performed in the midline of thoracic spine between T7 and T9 using the same technique as during supine CPR (Figure 2). The patient must be on a hard surface. Thus, the use of sandbags, serum bags, or even the clenched fist of a rescuer placed under the sternum may be helpful.^{1,9,10,13,48} In patients with a midline surgical incision such as for posterior lumbar fusion, prone chest compression with 1 hand on each side of the incision has been successfully used.¹⁴ Furthermore, adhesive defibrillator pads can be placed in both armpits or one on the left axillary midline and the other above the right scapula (Figure 3).^{19,48–55}

Patients positioned prone due to severe COVID-19 lung injury may also benefit from prone CPR. In addition to more rapid initiation of prone CPR cycling hypoxemic patients from prone to supine may aggravate hypoxemia due to disconnection from the ventilator and loss of positive end-expiratory pressure. In 136 patients with severe COVID who suffered CRA during their hospitalization, 113 occurred in the hospital ward and 23 in the ICU. Of these, 18 patients achieved ROSC. Unfortunately, the study does not clarify whether patients were receiving mechanical ventilation in the prone position when CRA occurred.⁵⁶

Observational studies and case reports included in this systematic review suggest that basic CPR and



Figure 3. Location where defibrillation pads should be placed in the prone position.

advanced CPR in the prone position provide hemodynamic and ventilatory support comparable to supine CPR. In addition, prone CPR is the only plausible option for patients who cannot be repositioned to supine, such as patients mechanically ventilated in prone position due to hypoxemic respiratory failure from COVID-19 or other causes. Further work is needed to determine whether administration of prone CPR is effective under real-world conditions and for what patient populations. ■

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DISCLOSURES

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