Available online at www.sciencedirect.com

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

Review

Prone cardiopulmonary resuscitation: A scoping and expanded grey literature review for the COVID-19 pandemic

Matthew J. Douma[a,b,1,*], *Ella MacKenzie*[g,1], *Tess Loch*[c], *Maria C. Tan*[d], *Dustin Anderson*[a], *Christopher Picard*[e], *Lazar Milovanovic*[a], *Domhnall O'Dochartaigh*[f], *Peter G. Brindley*[a]

[a] *Department of Critical Care Medicine, Faculty of Medicine and Dentistry, University of Alberta, Canada*
[b] *Alberta Health Services, Canada*
[c] *Cumming School of Medicine, University of Calgary, Canada*
[d] *John W Scott Health Sciences Library, University of Alberta, Canada*
[e] *University of Alberta, Faculty of Nursing & Covenant Health, Canada*
[f] *Edmonton Zone Emergency Departments, Alberta Health Services, Shock Trauma Air Rescue Society, Edmonton, Alberta, Canada*
[g] *RescueScience, Edmonton, Alberta, Canada*

Abstract

Aim: To identify and summarize the available science on prone resuscitation. To determine the value of undertaking a systematic review on this topic; and to identify knowledge gaps to aid future research, education and guidelines.

Methods: This review was guided by specific methodological framework and reporting items (PRISMA-ScR). We included studies, cases and grey literature regarding prone position and CPR/cardiac arrest. The databases searched were MEDLINE, Embase, CINAHL, Cochrane CENTRAL, Cochrane Database of Systematic Reviews, Scopus and Google Scholar. Expanded grey literature searching included internet search engine, targeted websites and social media.

Results: Of 453 identified studies, 24 (5%) studies met our inclusion criteria. There were four prone resuscitation-relevant studies examining: blood and tidal volumes generated by prone compressions; prone compression quality metrics on a manikin; and chest computed tomography scans for compression landmarking. Twenty case reports/series described the resuscitation of 25 prone patients. Prone compression quality was assessed by invasive blood pressure monitoring, exhaled carbon dioxide and pulse palpation. Recommended compression location was zero-to-two vertebral segments below the scapulae. Twenty of 25 cases (80%) survived prone resuscitation, although few cases reported long term outcome (neurological status at hospital discharge). Seven cases described full neurological recovery.

Conclusion: This scoping review did not identify sufficient evidence to justify a systematic review or modified resuscitation guidelines. It remains reasonable to initiate resuscitation in the prone position if turning the patient supine would lead to delays or risk to providers or patients. Prone resuscitation quality can be judged using end-tidal CO_2, and arterial pressure tracing, with patients turned supine if insufficient.

Keywords: CPR, Prone, Cardiopulmonary resuscitation, Scoping review, Resuscitation, COVID-19, SARS-CoV-2

* Corresponding author at: Department of Critical Care Medicine, Faculty of Medicine and Dentistry, University of Alberta, Canada.
E-mail address: douma@ualberta.ca (M.J. Douma).
[1] www.RescueScience.org.

https://doi.org/10.1016/j.resuscitation.2020.07.010
Received 23 May 2020; Received in revised form 29 June 2020; Accepted 11 July 2020
0300-9572/© 2020 Elsevier B.V. All rights reserved.

Introduction

For patients to have the best chance of surviving sudden cardiac arrest, high quality chest compressions and defibrillation need to be initiated without delay.[1] Traditionally, cardiopulmonary resuscitation (CPR) is taught and performed in the supine position, but even short delays- such as would occur if proned patients are first turned to the supine position — can be clinically detrimental.[2] The question of whether to supine patients before initiating resuscitation has long been relevant for out-of-hospital arrest patients found face down, and for intraoperative arrests during prone surgeries i.e. spine surgery, neurosurgery, retroperitoneal surgery. More recently, there has been an increase in prone mechanical ventilation in Intensive Care Unit (ICU) patients, since the 2013 Prone Positioning in Severe Acute Respiratory Distress Syndrome trial.[3] Since the COVID-19 pandemic, however, the issue of prone resuscitation has become especially important.[4] This is because, while we await robust evidence, prone positioning has been recommended in both confirmed and suspected cases, and in severely-ill/sedated patients and less ill/awake patients.[5–9]

'Flipping' a patient from prone to supine, especially during an emergency, comes with potential risks to both patient and staff.[10] Other than time delay, there could be endotracheal tube dislodgement, disconnection of vascular lines, disconnection of ventilation tubing, and staff contamination. There is also the mechanical challenge of turning obese patients, and potential injury to staff and patients. Especially relevant during pandemics, rolling a patient means that extra people (often six in total) enter a potentially contaminated space. There means extra delays until all of these staff have appropriately donned protective equipment, and the cumulative risks associated with doffing.

While almost all practitioners will supine patients before attempting an advanced airway, there is an initial period where compressions and defibrillation are performed before airway capture or supplementary breaths. Moreover, resuscitation guidelines have acknowledged that there are incidences where initiation of non-supine resuscitation is appropriate.[11] To date, most frontline clinicians have limited knowledge of the literature surrounding prone resuscitation. This is noteworthy now that proning is increasing. The goal of this scoping review is to assist clinicians forced to decide, in the midst of an emergency, whether CPR should be initiated with the patient 'proned', or whether the risks and delays of 'supine-ing' are unavoidable. More specifically, our objectives are: (i) to examine the extent of research into prone resuscitation, (ii) determine the value of undertaking a full systematic review, (iii) summarize and disseminate research related to prone resuscitation, (iv) and identify strategic gaps in the literature to aid future research, education and guidelines. Scoping review methods were selected (instead of systematic review) to identify available evidence types, clarify concepts, identify and analyse knowledge gaps. Furthermore a scoping review can determine if adequate research exists to undertake and systematic review, meta-analysis and risk of bias assessments that can inform guidelines and decision making.

Methods

This scoping review followed the methodological framework of Arksey and O'Malley and the enhancements of Levac et al.[12,13] It incorporated six steps: (i) research question identification, (ii) relevant study identification, (iii) selection of studies, (iv) charting the data, (v) collate, summarize and report results, and (vi) contributor provided references. Furthermore, this review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR).[14] Our findings are presented in tabular format, accompanied by narrative summaries.

Search strategy and inclusion criteria

The search strategy aimed to locate published and unpublished primary studies, reviews and grey literature such as policy, procedure and social media. We constructed a minimally-restrictive review question following the "PICO" format: for (p) patients (or manikins or cadavers) in the prone position in at the time of cardiac arrest (real or simulated), (i) who receive cardiopulmonary resuscitation, (c) no comparison criteria, and (o) any outcome. Full strategy is available in Appendix 1 (Supplementary material). Studies were eligible if they were peer-reviewed and examined or reported any characteristic or outcome of interest to prone CPR. Both qualitative and quantitative studies were eligible for inclusion. Studies using animal models of prone CPR were excluded.

Data sources

A systematic literature search was conducted by a health sciences librarian (MCT) using the following bibliographic databases: Ovid Medline ALL, Ovid Embase, EBSCOHost CINAHL Plus With full Text, Wiley Cochrane Central Register of Controlled Trials, Wiley Cochrane Database of Systematic Reviews, and Scopus. The search included a combination of controlled vocabulary (e.g., MeSH) and keywords representing the concepts of prone positioning and CPR/compressions. There were no limits on language, date, or study design. The MEDLINE search strategy was developed by the librarian and principal investigator (MJD), then translated for each database, and conducted on April 25, 2020. We also hand-searched bibliographies from previous systematic reviews for eligible studies. Multiple structured searches of Google Scholar were also performed and experts reviewed our search strategy and helped identify any missing articles.

Grey literature, such as regulatory data, unpublished trial data, government publications, policy and procedure, was searched in addition to the published peer reviewed literature to ensure the retrieval of all relevant evidence that may not indexed in traditional bibliographic databases. Our systematic grey literature search strategy was designed by author MD and followed previously accepted, peer-reviewed, methods.[15] It consisted of four parts: (i) internet search engine (Chrome anonymous browser for de-personalized Google search without geographical bias) (EM), (ii) targeted website searching of emergency department, critical care and resuscitation organizations (TC), (iii) grey literature database searching (KS & EM), and (iv) social media platform searching, including blogs (DOD). Grey literature sources were identified using accepted resources.[16] The purpose of our grey literature search was: (i) to identify relevant cases of prone resuscitation and inquire as to their publication and (ii) gain insight from relevant policy, procedure and clinical governance documents. Our grey literature search strategy is detailed in Appendix 2 (Supplementary material).

Study selection

References were imported to Covidence [Vertias Health Innovation, Melbourne, Australia] for deduplication, title, abstract, and full text

screening. Authors DA, MJD, DOD and LM independently screened titles, abstracts and full text articles against the selection criteria. Disagreements were resolved by discussion and consensus.

Data extraction and charting

Data were extracted by a single author (EM) and ratified by co-authors (TC and CP). Data were extracted into a Google Spreadsheet [Google, Mountain View California, USA]. An a priori data extraction table used to describe the characteristics of each study including: the authors(s), year of publication, study design, country, population, intervention and comparator (if applicable), major finding and outcome (s) examined. Data extracted from case reports/series included author, year, age, sex, diagnosis, type of surgery, initial rhythm, CPR quality and outcome (MJD and PGB).

Results

The search process retrieved 327 references from bibliographic databases. Once duplicates were removed, 202 references remained. An additional 126 references were identified from other sources as per the methods described above. A further 59 duplicates were identified and removed, resulting in a total of 269 items for title and abstract screening. After applying the inclusion/exclusion criteria to titles/abstracts, 46 articles underwent full text screening. Subsequently, 22 more articles were excluded for the following reasons: the patient was returned to the supine position prior to initiating resuscitation (n = 6), cardiac arrest could not be confirmed (n = 6), no new data was presented (n = 4), data was from a pilot of a study already included (n = 2), no resuscitation was attempted (n = 2), or we were unable to obtain a full text article (n = 2). See PRISMA flow sheet (Fig. 1) for more details. Overall, of 453 identified studies, 24 (5%) studies met our inclusion criteria and underwent extraction and narrative summary.[17–40]

Study characteristics

Four original research studies met inclusion criteria: (i) a feasibility study of blood pressure during supine versus prone compressions in six intensive care patients after prolonged cardiac arrest;[37] (ii) a study of cadavers (n = 11) and healthy volunteers (n = 10) on blood pressures and tidal volumes generated by prone compressions;[38] (iii) a prone compression quality manikin study;[39] and (iv) a retrospective descriptive study of chest computed tomography scans of 100 patients to identify ideal prone compression hand position.[40] Refer to Table 1 for summary table of included research.

Case reports/series characteristics

Twenty case reports/series describe 25 prone patients undergoing resuscitation including compressions.[17–36] All but five occurred in an operating theatre.[22,36] Over half involved pediatric patients (n = 14).[19,24,26–28,30,32,33,35,36] The arrest precipitant was

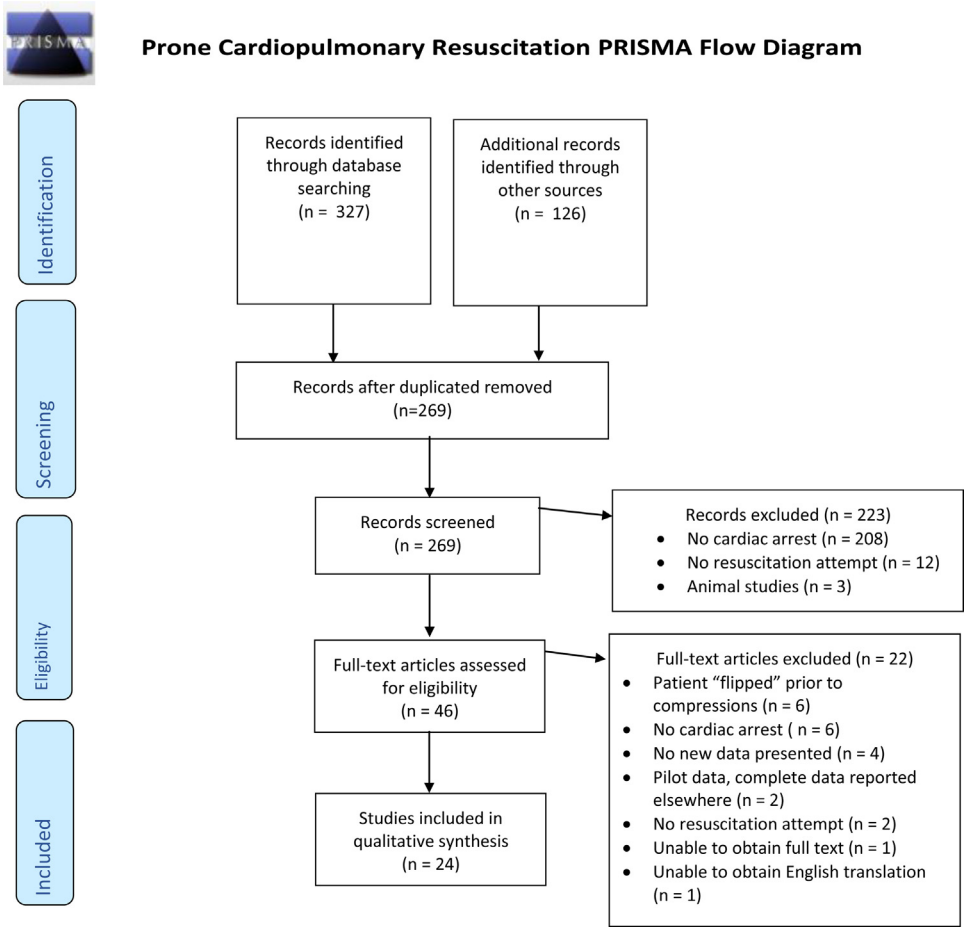


Fig. 1 – Prone cardiopulmonary resuscitation PRISMA flow diagram.

Table 1 – Details of included original studies.

Author, year	Design, country	Population	Intervention/comparator	Outcomes
Atkinson, 2000[39]	Feasibility trial; Edinburgh, Scotland	36 registered nurses	Nurses performed 100 compressions on a manikin with a gel-filled pad between sternum and standard examination couch. Landmark was midline ~2/3 up the body of the manikin i.e. "between imaginary scapula".	3376 chest compressions: 1168 (34.6%) effective (4–5 cm compression), 1370 (40.6%) partially effective (2–4 cm), 838 (24.6%) ineffective (<2 cm depth). 22/36 (61%) nurses able to deliver effective compressions (mean of 53% compressions were effective). Wide variations in compression effectiveness.
Kwon, 2017[40]	Retrospective descriptive study; Seoul, Republic of Korea	100 proned patients (54 male; 46 female; mean age 63 ± 12 years).	Single investigator, retrospective chest CT images of 100 prone patients: to identify the surface anatomical landmark, and approximate hand position during prone CPR.	Largest LV cross-sectional area is 0–2 vertebral segments below inferior angle of the scapulae in 86% of proned patients.
Mazer, 2003[37]	Pilot feasibility study, participants not blinded to blood pressure; New York, USA	6 adult ICU patients enrolled over 1 year from CICU (n = 4) and MICU (n = 2); 4 male; 2 female.	15 min of supine compressions then rolled for 15 min of prone compression (hands over the T7 –10 vertebrae).	SBP improved 48 mmHg–72 mmHg, MAP from 32 mmHg to 46 mmHg from supine to prone. No survivors and no ROSC.
Wei, 2006[38]	Part 1: cadavers. Part 2: healthy volunteers. Taiwan	Part 1: 11 cadavers (mean body weight 65.4 ± 9.0 kg).	Part 1: standard pre-cordial cardiac massage, then prone compressions.	Part 1: Prone CPR resulted in SBP 79.4 ± 20.3 mmHg, and DBP 16.7 ± 10.3 mmHg. Supine CPR produced increase in SBP of 55.4 ± 20.3/13.0 ± 6.7 mmHg to (79 ± 20/17 ± 10) (P = 0.028).
		Part 2: 10 healthy volunteers (mean body weight 63.3 ± 14.7 kg)	Part 2: respiratory assessment during prone compressions.	Part 2: External back compression on volunteers generated a mean tidal volume of 399 ± 110 mL.

Abbreviations: BP – blood pressure; CICU – cardiac intensive care unit; CPR – cardiopulmonary resuscitation; CT – computed tomography; DBP – diastolic blood pressure; $ETCO_2$ – end tidal carbon dioxide; ETT – endotracheal tube; ICU – intensive care unit; IV – intravenous; LV – left ventricle; MAP – mean arterial pressure; MICU – medical intensive care unit; PEA – pulseless electrical activity; ROSC – return of spontaneous circulation; TTE – transthoracic echocardiography; SBP – systolic blood pressure; SVT – supraventricular tachycardia; VF – ventricular fibrillation.

incompletely described, but, five patients had air emboli,[26,28,29,33] three had cardiac decompensation,[17,25,35] three had airway obstruction,[32,36] two had excessive parasympathetic stimulation[27,32] and one had cardiac tamponade.[31] The most common initial rhythm was pulseless electrical activity (n = 11, 44%),[17–21,23–26,32] followed by asystole (n = 4, 16%).[22,29,33] Refer to Table 2 for summary table of included cases.

Prone compression quality

Compression quality was assessed by invasive blood pressure monitoring, exhaled carbon dioxide and pulse palpation. A 2003 single-center case series reports of patients in intensive care with prolonged cardiac prone CPR was associated with improvements in both systolic (23 ± 14 mmHg, $p < 0.05$) and mean arterial blood pressure (14 ± 11 mmHg, $p < 0.05$)[37] In a fresh cadaver study, Wei et al. (2006) found similarly greater systolic and diastolic blood pressures (SDP, DBP) in the prone (79 ± 20 /17 ± 10 mmHg) versus supine (55 ± 20/13 ± 7 mmHg) position p = 0.028).[38] In five cases, prone compressions generated SBPs over 80 mmHg.[18,22,32,35] In one case, SBP did not rise above 40 mmHg in one case,[28] and in a cardiac arrest following air embolus, prone compressions produced a central venous but no arterial waveform.[33]

During craniotomy for acute cerebellar hemorrhage in an octogenarian, an $EtCO_2$ of 33 mmHg was achieved during prone compressions for an arrest linked to right-sided cardiac decompensation.[25] During a microscopic discectomy in a 43 year old, an $EtCO_2$ level of 28 mmHg was achieved during prone compressions following cardiac arrest of unknown cause.[23] Two additional cases reported $EtCO_2$ of 15 and <10,[24,34] and AlHarbi reported lower EtCO2 in the prone position than supine.[17]

Tidal volumes generated by prone compressions

One study examined the effect of prone compressions on tidal volumes.[38] In healthy volunteers, external back compressions generated mean tidal volumes of 399 ± 110 mL in five male and five female volunteers.[38]

Landmarking and hand position

In order to ascertain the best position for prone compressions, one study retrospectively reviewed chest computed tomography (CT) to correlate the surface landmarks overlying the left ventricle.[40] The largest left ventricle cross-section area was determined to be zero to two vertebral segments below the inferior angle of the scapula in at least 86% of patients in the prone position.[40]

Survival

Twenty of the 25 cases (80%) were associated with post-resuscitation survival, although few cases included long term outcome.[17,18,20–24,26,28–32,34–36] The most commonly reported survival endpoint was alive at the end of surgery,[17–28,30–32,34] followed by survival to hospital discharge,[18,25,28,31] and seven cases reported full neurological recovery.[18,24,30,31,34–36]

Table 2 – Characteristics of included case studies.

Author, year	Age	Sex	Diagnosis	Type of surgery	Rhythm	Confirmation of CPR quality	Cause of arrest	Outcome (neurological ideally)
Al Harbi, 2020[17]	80	Male	Spine surgery	Posterior spinal fusion with laminectomy	PEA, asystole	$ETCO_2$ 10 mmHg with prone CPR but no palpable pulse. When switched to supine, $ETCO_2$ increased & had palpable CPR pulses	Intraoperative NSTEMI due to hypovolemia	Survived
Brock-Utne, 2011[18]	28	Male	Pelvic fractures	Open reduction internal fixation	PEA	Systolic pressures over 80 mmHg (from arterial wave form)	Pulmonary embolus	Survived (discharged from hospital with intact neurologic status)
Burki, 2017[19]	6	Female	Ventricle tumor excision	Posterior cranial fossa	PEA	Not discussed	Hemorrhagic shock	ROSC, died 5 days post-surgery
Chauhan, 2016[20]	49	Male	Prolapsed intervertebral disc	Lumbar discectomy	PEA, asystole	Not discussed	Unknown	Survived
Cho, 2010[21]	18	Female	Congenital posterior scoliosis	Deformity correction and fusion with instrumentation	PEA, VF	Not discussed	Unknown	Survived
Dequin, 1996[22]	48	Male	Pneumonia	Prone ICU ventilation	Asystole	Arterial BP $>$ 80/35 mmHg throughout CPR	Unknown	Survived
Dooney, 2010[23]	43	Male	Left lower leg pain and weakness	L4–L5 microscopic discectomy	Bradycardic PEA to asystole	$ETCO_2$ = 28 mmHg	Unknown	Survived
Gueugniaud, 1995[24]	15	Male	Marfan's syndrome	Correction of a right dorsal and left lumbar scoliosis	PEA to asystole. Prone CPR to Supine CPR then ROSC	No palpable carotid pulse, $ETCO_2 < 10$ mmHg	Unknown	Survived, extubated after 18 h, full neurologic recovery
Haffner, 2010[25]	81	Male	Cerebellar hemorrhage	Craniotomy with acute cerebellar hemorrhage	PEA	$ETCO_2$ 33 mmHg with compressions. Visible arterial BP waveform correlated with CPR	TTE confirmed intraoperative right cardiac decompensation	Vasopressors weaned day 2, recovered some neurologic function. Rearrested & died 1-month post discharge
Kaloria, 2017[26]	1	Female	Split cord malformation type1 with tethered cord	Tethered cord release and bone spur removal	Bradycardic PEA	Not discussed	Massive venous air embolus	Survived
Kaur, 2016[27]	14	Male	Koch's spine	Thoracic spine deformity correction	Severe bradycardia to asystole	Not discussed	Parasympathetic stimulation	CPRx4 min then ROSC. Re-Arrested at 12 h and died
Kelleher, 1995[28]	6 months	Female	Achondroplasia, congenital cervical cord compression	Foramen magnum decompression	Multifocal PVCs, bradycardia, asystole. 7 m prone CPR then ROSC. PEA after 10 min ROSC, prone	Invasive BP with 40 mmHg waveform correlated to compressions	Hemorrhage and venous air embolus in coronaries	Survived, ICU discharge day 7. Mild cognitive delay.

(continued on next page)

Table 2 *(continued)*

Author, year	Age	Sex	Diagnosis	Type of surgery	Rhythm	Confirmation of CPR quality	Cause of arrest	Outcome (neurological ideally)
					CPR x4 min then ROSC			
Loewenthal, 1993[29]	53	Female	Meningioma	Craniotomy	Asystole, prone CPR x3 min then ROSC	Palpable femoral pulse correlated to CPR	Venous air embolus	Survived
Mayorga-Buiza, 2018[30]	10	N/a	Posterior fossa tumor	Posterior fossa tumor excision	Pulseless SVT to VF. CPR x8 min then ROSC	Not discussed	Not discussed	Survived
Mishra, 2019[31]	35	Female	C2–C3 intradural extramedullary meningioma	Laminectomy and tumor excision	Rhythm not discussed. Prone CPR x1m, then flipped for supine CPR x2m then ROSC	Not discussed	Cardiac tamponade	Survived to discharge.
Sun, 1992[32]	14	Female	Open occipital fracture with left intracerebellar hematoma	Posterior fossa craniectomy	Bradycardia, PEA, idioventricular	Arterial line systolic pressure throughout: 100–160 mmHg.	Torn transverse sinus, blood loss, brain retraction progressing to severe bradycardia and hypotension	Survived, uneventful recovery
Sun, 1992[32]	34	Male	Compression fracture of third cervical vertebrae, incomplete severance of cervical spinal cord	Decompression laminectomy	PEA, VF	Arterial systolic pressure throughout: 120–200 mmHg	Endotracheal tube occlusion	Survived, uneventful recovery
Sutherland, 1997[33]	8	Female	Limb girdle muscular dystrophy, progressive 55″ thoraco-lumbar scoliosis	T1-sacrum posterior spinal fusion with sublaminar wiring	Asystole	CPR produced central venous pressure waveform but no arterial waveform	Air embolus	Deceased
Sutherland, 1997[33]	12	Female	Athetoid cerebral palsy, 90″ progressive thoraco-lumbar scoliosis	T2-sacrum posterior spinal fusion with sublaminar wiring	Asystole	Not discussed	Air embolus	Deceased
Taylor, 2013[34]	69	Male	Metastatic melanoma and hypertrophic cardiomyopathy	posterior craniotomy	VT, progressed into VF	Pulsatile pressure tracing visible on the arterial line, and an $ETCO_2$ of 15 mmHg.	Unknown	Survived, full neurologic recovery
Tobias, 1994[35]	12	Male	Spastic quadriplegia, progressive scoliosis.	Spinal fusion	Bradycardia, asystole, idioventricular	Compressions pressures of 80–90 mm Hg from both arterial line and non-invasive BP cuff.	>4 L blood loss: abrupt decrease in MAP to 40 mmHg.	Survived, no change in neurologic status
Woo-Ming 1966[36]	2	Male	Whooping cough	n/a	No monitoring	Not discussed	Airway occlusion	Survived
Woo-Ming 1966[36]	3	Female	Stridor due to laryngeal diphtheria	Emergency tracheostomy	No monitoring	Not discussed	Laryngeal diphtheria	Survived, no deficits

Table 2 (continued)

Author, year	Age	Sex	Diagnosis	Type of surgery	Rhythm	Confirmation of CPR quality	Cause of arrest	Outcome (neurological ideally)
Woo-Ming 1966[36]	3 month	Male	Respiratory tract infection	n/a	No monitoring	Not discussed	Hypovolemia, air-way occlusion	Survived
Woo-Ming 1966[36]	7 weeks	Male	Staphylococcal pneumonia	n/a	No monitoring	Not discussed	Unknown	Survived

Abbreviations: PEA – pulseless electrical activity; VF – ventricular fibrillation; SVT – supraventricular tachycardia; M – minute(s); ROSC – return of spontaneous circulation; TTE – transthoracic echocardiogram.

Discussion

Despite growing interest in prone positioning, most healthcare professionals are unfamiliar with prone CPR. Accordingly, any practice change would need widespread education and practice. This, in turn, should be justified by robust evidence. Our review highlights that there may be more supportive literature than many clinicians realize, but also many important gaps. The first recommendation for prone CPR was over three decades ago (1989),[41] meaning the concept is not new. What has changed is its importance: because more patients will be 'proned' due to COVID-19, and because this practice may continue henceforth. In short, an increase in proning could mean more cardiac arrests in the prone position.

Presumably, the most pressing question is whether patients survive when resuscitated proned. After all, if universally unsuccessful then it should not be performed, or we need to accept/minimize the risks and delays associated with 'supine-ing' patients. The first concern is that the available guidance is predominantly from single cases or case series. Studies have also yet to widely encompass the sickest ICU patients. These ICU patients often have low post-arrest survival, because of multiorgan impairment and because the arrest commonly occurs despite aggressive preemption. This means that even before COVID-19, ICU practitioners faced uncertainty regarding whether to perform default CPR. They now have added risk to themselves, and responsibility to keep their teams safe. Overall, practitioners must currently extrapolate from the operating room experience. Brown et al. reviewed 22 case reports of prone cardiac arrests, 10 of whom survived to discharge,[42] and Mazer et al. and Wei et al. found prone compressions generated a higher systolic and mean arterial pressure during circulatory arrest in ICU patients compared to standard CPR.[37,38] Overall, when blood pressures were reported there appeared to be improvements in the prone position, (five of six patients in the Mazer et al. study and seven out of eight in the Wei et al. study).[37,38] The certainty of these findings however are very low due to the design and methodology of these small studies.

In terms of guidelines, and despite the dearth of data, the UK Resuscitation Council does recommend starting chest compressions without changing the position for adult patients who arrest during neurosurgery.[43] They added that the efficacy of CPR should be judged using the end-tidal CO_2 monitor, and the arterial pressure waveform. Prudently, they advise that patients be turned quickly supine if feedback from these monitors is judged insufficient. The 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care are more circumspect but still recommended: 'when patients cannot be placed in the supine position, it may be reasonable for rescuers to provide CPR in the prone position, particularly in hospitalized patients with an advanced airway'.[11]

The next issue concerns optimum technique for prone chest compressions. The Resuscitation Council and American Heart Association make no specific recommendations. However, the first two cases of successful prone chest compressions (in neurosurgical patients) were published in 1992 by Sun et al., using what they called 'reversed precordial compression'.[32] In everyday language, this means compressing over the mid-thoracic spine plus a hand under the lower sternum: for counter-pressure.[32] Similarly, Dequin et al. reported successful prone CPR in an ICU patient, in which they used two-handed mid-thoracic compression and a second person for sternal counter-pressure.[22] Gomes and Bersot reported successful

prone CPR in a neurosurgical patient, using compression over the mid-thoracic level, but no sternal counter-pressure.[44] Kwon et al. reviewed 100 chest CTs to determine where to compress the largest left ventricular mass. Once again, it was mid-thoracic, below the inferior angle of the scapulae.[40]

In 2020, guidelines were expedited by the UK's Faculty of Intensive Care Medicine and Intensive Care Society, spurred by the COVID-19 pandemic.[10] These organizations jointly recommend a two-handed technique over the mid-thoracic spine, and between the two scapulae. The use of a second person to apply counter-pressure is optional. Given the added logistics, the contamination risk, and the overall recommendation to limit resuscitator in the room, we would recommend against this additional step.

Clearly, our scoping review has limitations which limit its generalizability. These include a general lack of studies, a focus on operating theatre patients and a preponderance of witnessed arrests. The evidence is mostly from cases, and is therefore of comparatively low quality and predates the 2015 resuscitation guidelines. We also had to rely upon Google Translate for one French, one German and one Korean case report. Regardless, rather than prone resuscitation being as an area of niche interest, we believe our modest scoping review has highlighted an area of increasingly clinical relevance and research priority.

Conclusion

This scoping review demonstrated that the majority of published literature on prone resuscitation are neurosurgical cases with positive outcomes. Although this scoping review has not identified sufficient evidence to prompt a systematic reviews or reconsideration of current guidelines, it pinpoints gaps in the research evidence related to prone resuscitation, namely a lack of moderate to high-level evidence and paucity of studies of out-of-hospital cardiac arrest. We hope this review can help inform the care of prone patients during the COVID-19 pandemic should they require resuscitation.

Author statement

Our writing team take responsibility for and approve the submitted manuscript. All authors meet ICMJE authorship criteria.

Competing interests

The authors have no conflicts of interest relevant to this article to disclose.

Funding

This scoping review was unfunded.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2020.07.010.

REFERENCES

1. Zhan L, Yang LJ, Huang Y, He Q, Liu GJ. Continuous chest compression versus interrupted chest compression for cardiopulmonary resuscitation of non-asphyxial out-of-hospital cardiac arrest. Cochrane Database Syst Rev 20173:, doi:http://dx.doi.org/10.1002/14651858.CD010134.pub2 Art. No.: CD010134.
2. Bamford P, Denmade C, Newmarch C, et al. Guidance for: prone positioning in adult critical Care. 2019.
3. Parker AM, Guerin C, PROSEVA Study Group, et al. Prone positioning in severe acute respiratory distress syndrome. Am J Respir Crit Care Med 2014;189:223–4, doi:http://dx.doi.org/10.1164/rccm.201308-1555RR.
4. Barker J, Koeckerling D, West R. A need for prone position CPR guidance for intubated and non-intubated patients during the COVID-19 pandemic. Resuscitation 2020;151:135–6, doi:http://dx.doi.org/10.1016/j.resuscitation.2020.04.029.
5. J. Farkas, PulmCrit - Awake Proning for COVID-19. *EMCrit Project*, 5 May 2020, https://emcrit.org/pulmcrit/awake-prone-covid/.
6. Caputo ND, Strayer RJ, Levitan R. Early self-proning in awake, non-intubated patients in the emergency department: a single ED's experience during the COVID-19 pandemic. Acad Emerg Med 2020;27:375–8, doi:http://dx.doi.org/10.1111/acem.13994.
7. Valter C, Christensen AM, Tollund C, SchOnemann NK. Response to the prone position in spontaneously breathing patients with hypoxemic respiratory failure. Acta Anaesthesiol Scand 2003;47:416–8, doi:http://dx.doi.org/10.1034/j.1399-6576.2003.00088.x.
8. Pérez-Nieto OR, Guerrero-Gutiérrez MA, Deloya-Tomas E, Ñamendys-Silva SA. Prone positioning combined with high-flow nasal cannula in severe noninfectious ARDS. Crit Care 2020;24:114, doi:http://dx.doi.org/10.1186/s13054-020-2821-y.
9. Scaravilli V, Grasselli G, Castagna L, et al. Prone positioning improves oxygenation in spontaneously breathing nonintubated patients with hypoxemic acute respiratory failure: a retrospective study. J Crit Care 2015;30:1390–4, doi:http://dx.doi.org/10.1016/j.jcrc.2015.07.008.
10. The Faculty of Intensive Care Medicine, The Intensive Care Society. Guidance for: prone positioning in adult critical care. 2019.
11. Cave DM, Gazmuri RJ, Otto CW, et al. Part 7: CPR techniques and devices: 2010 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2010;122:S720–728, doi:http://dx.doi.org/10.1161/CIRCULATIONAHA.110.970970.
12. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol 2005;8:19–32, doi:http://dx.doi.org/10.1080/1364557032000119616.
13. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. Implement Sci 20105:, doi:http://dx.doi.org/10.1186/1748-5908-5-69.
14. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 2018;169:467, doi:http://dx.doi.org/10.7326/M18-0850.
15. Godin KM, Kirkpatrick SI, Hanning RM, Stapleton J, Leatherdale ST. Examining guidelines for school-based breakfast programs in Canada: a systematic review of the grey literature. Can J Diet Pract Res 2017;78:92–100, doi:http://dx.doi.org/10.3148/cjdpr-2016-037.
16. The Canadian Agancy for Grugs and Technologies in Health (CADTH). Grey matters: a practical tool for searching health-related grey literature [Internet]. 2018.
17. Al Harbi M, Alattas K, Alnajar M, Albuthi M. Prone cardiopulmonary resuscitation in elderly undergoing posterior spinal fusion with laminectomy. Saudi J Anaesth 2020;14:123, doi:http://dx.doi.org/10.4103/sja.SJA_165_19.
18. Brock-Utne JG. Case studies of near misses in clinical anesthesia. New York, NY: Springer New York; 2011, doi:http://dx.doi.org/10.1007/978-1-4419-1179-7.
19. Burki AM, Mahboob S, Fatima T. CPR in prone position during neurosurgery. Intensive Care 2017;21:4.

20. Chauhan V, Tiwari A, Rath GP, Banik S. Asystole during lumbar discectomy: a case report. J Clin Anesth 2016;31:265–6, doi:http://dx.doi.org/10.1016/j.jclinane.2016.01.014.
21. Cho S-J, Lee EH, Hwang J-Y, Park S-J, Hahn S-H, Kim J-H. Percutaneous cardiopulmonary support for the management of recurrent cardiac arrest during scoliosis correction surgery in the prone position — a case report. Anesth Pain Med 2012;7:41–4.
22. Dequin P-F, Hazouard E, Legras A, Lanotte R, Perrotin D. Cardiopulmonary resuscitation in the prone position: Kouwenhoven revisited. Intensive Care Med 199622:, doi:http://dx.doi.org/10.1007/BF01709349 1272–1272.
23. Dooney N. Prone CPR for transient asystole during lumbosacral spinal surgery. Anaesth Intensive Care 2010;38:212–3.
24. Gueugniaud P-Y, Muchada R, Bertin-Maghit M, Griffith N, Petit P. Non-invasive continuous haemodynamic andPetCO2 monitoring during peroperative cardiac arrest. Can J Anaesth 1995;42:910–3, doi:http://dx.doi.org/10.1007/BF03011039.
25. Haffner E, Sostarich AM, Fösel T. Erfolgreiche kardiopulmonale Reanimation in Bauchlage. Anaesthesist 2010;59:1099–101, doi:http://dx.doi.org/10.1007/s00101-010-1785-8.
26. Kaloria N, Bhagat H, Singla N. Venous air embolism during removal of bony spur in a child of split cord malformation. J Neurosci Rural Pract 2017;08:483–4, doi:http://dx.doi.org/10.4103/jnrp.jnrp_508_16.
27. Kaur J, Kane D, Shinde S, Dongre V. Abstract PR030: cardiac arrest in prone position; when do I make patient supine? Anesth Analg 2016;123:47, doi:http://dx.doi.org/10.1213/01.ane.0000492440.41192.e3.
28. Kelleher A, Mackersie A. Cardiac arrest and resuscitation of a 6-month old achondroplastic baby undergoing neurosurgery in the prone position. Anaesthesia 1995;50:348–50, doi:http://dx.doi.org/10.1111/j.1365-2044.1995.tb04615.x.
29. Loewenthal A, De Albuquerque AM, Lehmann-Meurice C, Otteni JC. Efficacité du massage cardiaque externe chez une patiente en décubitus ventral. Ann Fr Anesth Réanimation 1993;12:587–9, doi:http://dx.doi.org/10.1016/S0750-7658(05)80627-6.
30. Mayorga-Buiza MJ, Rivero-Garvia M, Gomez-Gonzalez E, Marquez-Rivas J. Cardiac pulmonary resuscitation in prone position. The best option for posterior fossa neurosurgical patients. Pediatr Anesth 2018;28:746–7, doi:http://dx.doi.org/10.1111/pan.13448.
31. Mishra N, Singh S, Elayat A, Kaushal A. Cardiac arrest in the prone position caused by central venous cannulation-induced cardiac tamponade. Korean J Anesthesiol 2019;72:394–5, doi:http://dx.doi.org/10.4097/kja.19105.
32. Sun W-Z, Huang F-Y, Kung K-L, Fan S-Z, Chen T-L. Successful cardiopulmonary resuscitation of two patients in the prone position using reversed precordial compression. Anesthesiology 1992;77:202–4, doi:http://dx.doi.org/10.1097/00000542-199207000-00027.
33. Sutherland RW, Winter RJ. Two cases of fatal air embolism in children undergoing scoliosis surgery. Acta Anaesthesiol Scand 1997;41:1073–6, doi:http://dx.doi.org/10.1111/j.1399-6576.1997.tb04839.x.
34. Taylor JCL, Buchanan CCR, Rumball MJ. Cardiac arrest during craniotomy in prone position. Trends Anaesth Crit Care 2013;3:224–6, doi:http://dx.doi.org/10.1016/j.tacc.2013.02.015.
35. Tobias JD, Mencio GA, Atwood R, Gurwitz GS. Intraoperative cardiopulmonary resuscitation in the prone position. J Pediatr Surg 1994;29:1537–8, doi:http://dx.doi.org/10.1016/0022-3468(94)90208-9.
36. Woo-Ming MO. Cardiorespiratory resuscitation in the prone position in small children. West Indian Med J 1966;15:197–201.
37. Mazer SP, Weisfeldt M, Bai D, et al. Reverse CPR: a pilot study of CPR in the prone position. Resuscitation 2003;57:279–85, doi:http://dx.doi.org/10.1016/S0300-9572(03)00037-6.
38. Wei J, Tung D, Sue S-H, Wu S-V, Chuang Y-C, Chang C-Y. Cardiopulmonary resuscitation in prone position: a simplified method for outpatients. J Chin Med Assoc 2006;69:202–6, doi:http://dx.doi.org/10.1016/S1726-4901(09)70219-9.
39. Atkinson MC. The efficacy of cardiopulmonary resuscitation in the prone position. Crit Care Resusc J Australas Acad Crit Care Med 2000;2:188–90.
40. Kwon M-J, Kim E-H, Song I-K, Lee J-H, Kim E-H, Kim J-T. Optimizing prone cardiopulmonary resuscitation: identifying the vertebral level correlating with the largest left ventricle cross-sectional area via computed tomography scan. Anesth Analg 2017;124:520–3, doi:http://dx.doi.org/10.1213/ANE.0000000000001369.
41. McNeil EL. Re-evaluation of cardiopulmonary resuscitation. Resuscitation 1989;18:1–5, doi:http://dx.doi.org/10.1016/0300-9572(89)90107-X.
42. Brown J, Rogers J, Soar J. Cardiac arrest during surgery and ventilation in the prone position: a case report and systematic review. Resuscitation 2001;50:233–8, doi:http://dx.doi.org/10.1016/S0300-9572(01)00362-8.
43. Carroll C, Davies R, Gwinnutt C, Kamaly-Asl I, Soar J. Management of cardiac arrest during neurosurgery in adults. 2014.
44. Gomes D de S, Bersot CDA. Cardiopulmonary resuscitation in the prone position. Open J Anesthesiol 2012;02:199–201, doi:http://dx.doi.org/10.4236/ojanes.2012.25045.