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Cardiopulmonary resuscitation in prone position: A scoping review

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Abstract

Introduction: The ongoing pandemic of COVID-19 brought to the fore prone positioning as treatment for patients with acute respiratory failure. With the increasing number of patients in prone position, both spontaneously breathing and mechanically ventilated, cardiac arrest in this position is more likely to occur. This scoping review aimed to summarize the available evidence on cardiopulmonary resuscitation in prone position ('reverse CPR') and knowledge or research gaps to be further evaluated. The protocol of this scoping review was prospectively registered on 10th May 2020 in Open Science Framework (https://osf.io/nfuh9).

Methods: We searched PubMed, EMBASE, MEDLINE and pre-print repositories (bioRxiv and medRxiv) for simulation, pre-clinical and clinical studies on reverse CPR until 31st May 2020.

Results: We included 1 study on manikins, 31 case reports (29 during surgery requiring prone position) and 2 nonrandomized studies describing reverse CPR. No studies were found regarding reverse CPR in patients with COVID-19.

Conclusions: Even if the algorithms provided by the guidelines on basic and advanced life support remain valid in cardiac arrest in prone position, differences exist in the methods of performing CPR. There is no clear evidence of superiority in terms of effectiveness of reverse compared to supine CPR in patients with cardiac arrest occurring in prone position. The quality of evidence is low and knowledge gaps (e.g. protocols, training of healthcare personnel, devices for skill acquisition) should be fulfilled by further research. Meanwhile, a case-by-case evaluation of patient and setting characteristics should guide the decision on how to start CPR in such cases.

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1. Introduction

Cardiopulmonary resuscitation (CPR) is the cornerstone of the treatment of cardiac arrest, improving patients’ chances of defibrillation and eventual survival [1]. The algorithms of cardiopulmonary resuscitation include the provision of high-quality chest compressions and rapid defibrillation [1]. Manual chest compressions are described as effective when delivered ‘in the centre of the chest’, with a depth of 5–6 cm, and at a rate of 100–120 min⁻¹, with less interruptions as possible and complete chest recoil after each compression [1].

These algorithms can be applied in most settings, with specific indications for special circumstances (e.g. drowning, hypothermia or hostile environments) [2]. Among the possible scenarios, cardiac arrest occurring in prone positioned patients may slightly increase the complexity of the procedures, with additional pitfalls.

The main aim for starting CPR in prone position, also known as ‘reverse CPR’, may be the reduction of the no flow time (blood flow to the heart or brain), since turning a prone patient into the supine position requires additional time and focusing (e.g. not to disconnect the patient from the ventilator during supination) and may delay resuscitation.

Prone position as treatment for acute respiratory distress syndrome (ARDS) has been firstly described in 1976 [3]. During the current coronavirus disease 2019 (COVID-19) pandemic, it has been widely used in both spontaneously breathing and mechanically ventilated patients with acute respiratory failure [4,5]. An increasing number of cardiac arrests [6] is expected during COVID-19 era in the prone position. Furthermore, coronavirus diseases 2019 (COVID-19) has resulted in the emergence of new clinical challenges in the context of cardiac arrest, as the time required for personal protective equipment (PPE) donning, the need to clamp endotracheal tubes or to temporarily stop mechanical ventilation.

Keywords:
Prone CPR
Reverse CPR
Prone position
COVID-19
ventilation to reduce rescuers’ exposure. These issues add complexity to the procedure [7].

This scoping review aimed to summarize the available evidence on the cardiopulmonary resuscitation in prone position (‘reverse CPR’) and to highlight possible knowledge or research gaps to be further evaluated.

2. Methods

2.1. Search strategy

For the purpose of this review, we searched PubMed, EMBASE, and MEDLINE for pre-clinical and clinical studies on prone CPR. Our search included the keywords “resuscitation”, “CPR”, “chest compression”, “cardiopulmonary”, “resuscitation”, “prone position” as exact phrases and a combination of broad subject headings according to databases syntax. Specifically, the EMBASE engine was used with the following query: (‘resuscitation’ OR ‘cpr’ OR ‘chest compression’/exp. OR ‘chest compression’ OR cardiopulmonary OR ‘resuscitation’/exp. OR resuscitation) AND (‘prone position’/exp. OR ‘prone position’ OR ‘prone positioning’/exp. OR ‘prone positioning’’ OR ‘prone’ OR ‘proneing’) in EMBASE, PubMed or MEDLINE.

A search was also conducted on main pre-print repositories (bioRxiv and medRxiv) from inception to 31st May 2020 for relevant studies. No limitations were imposed for specific contexts, with the aim of including surgical, medical and intensive care settings. Articles on animals or on manikins were also eligible. Randomized controlled trials (RCTs), nonrandomized studies (both prospective or retrospective), case series and case reports were included. Abstracts and conference proceedings were excluded. Snowballing search on the references of selected articles was also performed.

After the exclusion of duplicates and abstracts, two authors (AM, PI) independently screened full-text papers to include the most relevant on the topic and independently charted data using an electronic standardized form. In case of case reports or series describing more than one patient, we collected data only on patients meeting inclusion criteria (i.e. cardiac arrest occurring in prone position and CPR performed).

We collected data regarding the type of study (e.g. design and country), population characteristics at baseline (e.g. age, main disease), setting (e.g. operator room, ICU), occurred events (e.g. rhythm and cause of the cardiac arrest), intervention (e.g. prone or standard CPR) and outcomes (e.g. mortality, return of spontaneous circulation – ROSC). Data were then tabulated for presentation, as appropriate.

The protocol of this scoping review was prospectively registered on 10th May 2020 (https://osf.io/nfu9h). The scoping review was conducted following PRISMA statement extension for scoping reviews [8].

3. Results

The initial search identified 1301 results from EMBASE, PubMed and other sources. Following screening of titles and abstracts and removing duplicates, we evaluated 82 articles in full text. Among these, we selected and included 34 articles. The search from pre-print repositories (bioRxiv and medRxiv) resulted in 52 records screened, none included. The details on the inclusion/exclusion process are provided in the PRISMA flow diagram (see Fig. 1).

We found no RCT comparing prone to standard supine CPR. Three of the included studies [9–11] had a nonrandomized design and 31 were case reports [12–42]. In this section, the included nonrandomized studies are described: a complete description of all the studies, including case reports, is provided with details in Table 1.

The first study evaluating the feasibility of reverse CPR was a simulation study using Laerdal ‘ResusciAnne’ manikins, posed in prone position on a standard examination coach, with a gel pad under the sternum. Thirty-six trained nurses were asked to perform 100 compressions on the manikin with no breaks for respirations. Using a skillmeter, a total of 3376 compressions (91.8% of the 3600 total possible) were registered, but only 1168 (34.6%) were effective (4–5 cm compression depth), with 1370 (40.6%) partially effective (2–4 cm compression depth) and 838 (24.6%) ineffective (<2 cm compression depth) compressions. Only 9/36 nurses were able to perform 70% or more adequate compressions (usually considered as the acceptable threshold). An important insight was provided by the authors, discussing that all the nurses had judged CPR in the prone position as more tiring than in the standard position. This, in addition to the light weight of the manikin and the position of the nurses’ left-hand side of the manikin, may explain the low rate of successful compressions and the number of compressions performed off the midline (11.2% to the right of midline, 4.1% too high, 6.1% too low, none to the left of the midline). None of the eligible studies were conducted on animals.

Among the nonrandomized studies on humans, one was conducted on 11 cadavers and 10 healthy volunteers, evaluating indirect outcomes (blood pressure and tidal volume) [9]. Mean arterial pressure (MAP) was invasively measured in cadavers both during standard and consecutive back chest compressions (55 ± 20/13 ± 7 vs. 79 ± 20/17 ± 10 p = 0.028) performed at a rate of 60 per minute. Healthy volunteers’ tidal volume was then measured using a mouthpiece connected to a spirometer, while they were receiving back chest compressions (60 min⁻¹). Spontaneous breathing was held, and a nose clip applied on the volunteers. Mean registered tidal volume was of 399 ± 110 ml. The authors highlighted that their findings may support prone CPR in nonintubated patients, since airways open spontaneously, and adequate ventilation seems achievable with compressions only. Nonetheless, the study has limited external validity, especially for the finding regarding tidal volume (e.g. possibly not generalizable to patients with a compromised pulmonary function), requiring further investigations.

Another nonrandomized study enrolled six ICU patients in cardiac arrest, after the declared failure of standard CPR [10]. Main results included a systolic blood pressure mean improvement of 23 ± 14 mmHg, a calculated MAP mean improvement of 14 ± 11 mmHg and a diastolic blood pressure mean improvement of 10 ± 12 mmHg from standard to reverse CPR, but no cases of ROSC.

Despite such a limited basis, we retrieved a total of 31 case reports described in literature from 1982 (date of the first retrieved report) to date, for a total of 34 patients.

Among the included case reports, 29 described cardiac arrests occurred during surgery. Surgeries included spinal surgery in 20 patients (e.g. discectomies, scoliosis correction, vertebral metastases), cranietomy in 10 patients (e.g. primitive or metastatic cancer, hemorrhage), and cases of pelvic fracture and dorsal lipoplasty. One occurred in the ICU [33] in a prone positioned mechanically ventilated patient, admitted for community acquired pneumonia and acute respiratory failure. Another article reported a case of cardiac arrest during endoscopic
retrograde cholangiopancreatography procedure [22]. Fifteen of the described patients were children (≤16 years old), and three were infants (≤1 year old).

No studies were found regarding reverse CPR in patients with COVID-19.

4. Discussion

The feasibility of CPR in prone position has been under investigated. Its use has been described in the settings of both operatory rooms (e.g. neurosurgery, orthopedics) and ICUs (e.g. mechanically ventilated patients with respiratory failure), mainly on case reports.

The main finding of this scoping review is that there is insufficient evidence on the topic and further evidence is needed, considering that an increasing number of cardiac arrests in prone position are expected during the COVID-19 pandemic.

Many aspects, both decisional and technical, have been described but remain controversial and need to be investigated with adequately designed studies.

4.1. Available evidence

To date, evidence on reverse CPR comes from case reports and small sized nonrandomized studies conducted on manikins, cadavers, healthy volunteers or patients with previously failed standard CPR. Among the included reports, ROSC after reverse CPR occurred in 23 out of 31 cases, demonstrating that the technique may be effective and deserves further investigations. Nevertheless, publication bias may exist, potentially overestimating the rate of favorable outcomes in prone CPR, and potentially limiting our findings. We did not find any RCT on the topic and nonrandomized studies only provide preliminary and indirect data to support the technique. Despite prone CPR may be a feasible and safe option in specific settings, further literature is needed, with many aspects remaining uninvestigated.

4.2. Causes of cardiac arrest in prone position

From the evaluated articles, it can be argued that a frequent cause of cardiac arrest in prone position is air embolism, a potentially fatal event, often occurring in neurosurgery and closely related to the position of the patient and the presence of a pressure gradient allowing air flow into the vessels. Other causes are linked with the specific patient positioning, which can sometimes lead to vessel occlusion and reduced venous return. Hypovolemia in combination with reduced venous return can quickly lead to reduced cardiac output.

The rhythm presentation is various, ranging from asystole to pulseless electrical activity (PEA), or ventricular fibrillation (VF).
Table 1: Characteristics of the included studies.

| Author (Year) | Design | Setting; Country | Patients | Event and cause | Intervention | Results |
|---------------|--------|------------------|----------|----------------|-------------|---------|
| Al Harbi et al. (2020) [12] | Case report | Operating room (Posterior spinal fusion with laminectomy); Saudi Arabia | 80 years old male patient at intermediate cardiac risk | Two episodes of PEA at about 6 h from anesthesia induction. | First episode: CPR in prone position | First episode: ROSC, supination and second episode of cardiac arrest; Second episode: ROSC and ICU admission |
| Mishra et al. (2019) [13] | Case report | Operating room (Laminectomy and excision of a C2–C3 intradural extra-medullary meningioma); India | 35 years old female patient | Intraoperative cardiac arrest, due to cardiac tamponade | 1 min prone position CPR, followed by supination and standard CPR in prone position | ROSC, ICU admission with pericardial catheterism and negative suction; extubation at day 3 |
| Mayorga-Buiza et al. (2018) [14] | Case report | Operating room (Excision of a large tumour in the posterior fossa); Spain | 10 years old patient | Pulseless VT, thenVF during mobilization and resection of the tumour | CPR in prone position | ROSC followed by spinal hematoma, then surgically drained. Survived without sequelae at 24 months |
| Burki et al. (2017) [15] | Case report | Operating room (Fourth ventricle tumour excision); Pakistan | 6 years old female patient | Intraoperative cardiac arrest, due to massive bleeding (estimated blood loss 2 l) | CPR in prone position | Death at day 5 after surgery |
| Kaloria et al. (2017) [16] | Case report | Operating room (Tethered cord release and removal of bony spur); India | 1 year old girl | Electromechanical dissociation, possibly due to venous air embolism | CPR in prone position | ROSC, surgery completion, discharge at day 6 |
| Lee-Archer and Chaseling (2017) [17] | Case report | Operating room (Posterior spinal fusion C5 to 14, for severe kyphoscoliosis); Australia | 10 years old girl | Cardiac arrest during attempts to locate the epidural space with a loss of resistance air technique, possibly due to air embolism | Supination and standard CPR | ROSC, completion of surgery at day 4, right-sided brain infarction and left upper limb weakness, recovered after two weeks |
| Pinheiro et al. (2017) [18] | Case report | Operating room (Esthetic lipoplasty) | 25 years old female patient | Asystole | Supination and standard CPR in prone position | ROSC, surgery cancelled, ICU admission, discharge ROSC. Discharged home in stable neurological condition |
| Taylor et al. (2013) [19] | Case report | Operating room (Cranietomy for metastatic melanoma); New Zealand | 69 years old male patient with hypertrophic cardiomyopathy and impaired (34%) ejection fraction | Cardiac arrest, due to rupture of sagittal sinus and subsequent hemorrhagic shock | CPR in prone position | ROSC, ICU admission, discharge at day 3 |
| De Souza Gomez et al. (2012) [20] | Case report | Operating room (Excision of highly vascularized parietal-occipital meningioma on the right side); Brazil | 77 years old female patient | Asystole | CPR in prone position | ROSC, ICU admission, discharge at day 3 |
| Pan et al. (2012) [22] | Case report | Endoscopic room (ERCP) | 61 years old female patient | Intraprocedural cardiac arrest, due to venous air embolism | Supination and standard CPR | Death |
| Dooney (2010) [21] | Case report | Operating room (L4-L5 microscopic discectomy); South Australia | 43 years old male patient | Asystole | CPR in prone position | ROSC |
| Dumont et al. (2010) [23] | Case report | Operating room (Arthrodesis for atlantoaxial instability) | 38 years old male patient | Asystole, due to air embolism | Supination and standard CPR | ROSC, surgery completion, ICU admission and discharge without sequelae ROSC; ICU admission; death at day 28 |
| Haffner et al. (2010) [24] | Case report | Operating room (Emergency craniotomy for cerebellar hemorrhage) | 81 years old | Intraoperative cardiac arrest, possibly due to right heart failure | Prone CPR | ROSC, ICU admission; surgery completion three days later; discharged from the hospital with intact neurological status |
| Almazan et al. (2009) (personal communication reported by Brock-Utne in “Case Studies of Near Misses in Clinical Anesthesia” [25] | Case report | Operating room (Open reduction internal fixation for multiple pelvic fractures); NA | 28 years old male patient | PEA due to pulmonary embolism | CPR in prone position | ROSC, ICU admission; surgery completion three days later; discharged from the hospital with intact neurological status |
| Beltran and Mashour (2007) [26] | Case report | Operating room (Skullbase craniotomy for tumour debulking); USA | 21 years old female patient with neurofibromatosis type 2 | PEA due to sigmoid sinus disruption, leading to significant blood loss | Supination and standard CPR | Intraoperative death |
| Wei et al. (2006) [9] | Single-centre nonrandomized study | ICU/healthy volunteers; Taiwan | a. 11 patients who had died in ICU b. 10 alive and healthy volunteers | a. Death b. None | a. One minute precardial cardiac massage followed by one minute thoracic massage in prone position; b. Back thoracic | a. Mean blood pressure (invasively monitored) achieved with standard precardial compressions was 55 ± 20 / 13 ± 7 vs. 79 ± 20 / 17 ± 10 in prone position compression. b. Mean tidal volume with |
Table 1 (continued)

| Author (Year) | Design                  | Setting; Country                                                                 | Patients                                                                 | Event and cause                                                                 | Intervention                                                                 | Results                                                                 |
|---------------|-------------------------|----------------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------|
| Smelt (2005)  | Single-centre nonrandomized study | ICU; USA                                                                          | 6 patients with cardiac arrest, enrolled after failed standard CPR     | VT, then pulseless VF                                                          | Supination and standard CPR                                                | Intraoperative death                                                   |
| Mazer et al. (2003) | Case report          | Operating room (Thoracic spine decompression surgery for an invasive tumour between T11 and L1 vertebral levels); UK | 60 years old female patient                                             | Broad complex tachycardia followed by VT. Suspected cause: venous air embolism | Debridillation in prone position                                           | ROSC, completion of surgery, extubation on the following day, full recovery without sequelae |
| Miranda and Newton (2001) | Case report          | Operating room (Palliative debulking of metastatic tumour at T3 and internal fixation of the thoracic spine); UK | 39 years old female patient                                             | Intraoperative pulseless VF, possibly due to altered potassium levels          | Sharp thump in prone position, followed by CPR                            | ROSC, completion of surgery and discharge home at 1 week from the event |
| Brown et al. (2001) | Case report          | Operating room (Spinal surgery to correct progressive scoliosis)                  | 15 years old boy with Duchenne muscular dystrophy                      | Pulseless VF                                                                  | Left posterior thoracotomy and direct cardiac massage, then debridillation | ROSC, full recovery after ICU stay                                      |
| Sutherland and Winter (1997) | Case report          | Operating room (Surgical correction of a right dorsal and left lumbar scoliosis); France | 15 years old boy                                                       | a. Asystole due to massive venous air embolism                                | CPR begun in prone position and continued in supine position              | Intraoperative death                                                   |
| Dequin et al. (1996) | Case report          | ICU; France                                                                      | 48 years old male patient with CAP                                        | Asystole, occurred few minutes after prone positioning                        | CPR in prone position                                                     | ROSC, recovery at day 7 from the event                                  |
| Gueugniaud et al. (1995) | Case report          | Operating room (Surgical decompression with sublaminar wiring for a progressive scoliosis); b. T2-sacrum posterior spinal fusion with sublaminar wiring for a progressive scoliosis); UK | 6 months old achondroplastic baby with small patent foramen ovale and a left to right shunt | Intraoperative pulseless electromechanical dissociation followed by asystole, probably due to myocardial ischaemia | CPR in prone position, then supination                                   | ROSC, surgery postponed, full recovery without neurological sequelae  |
| Kellehe and Mackersie (1995) | Case report          | Operating room (Erector musculi thoracis and serratus anterior muscle); UK         | 15 years old boy                                                       | a. Asystole due to massive venous air embolism and estimated total blood loss of 1.1 l | CPR with fingers of one hand in prone position (two episodes)            | ROSC, ICU admission, discharge at day 7                                 |
| Tobias et al. (1994) | Case report          | Operating room (Spinal fusion for progressive)                                    | 12 years old boy with severe spastic                                    | Asystole, possibly due to large amount of blood                               | CPR in prone position                                                     | ROSC, ICU admission, uneventful postoperative                          |
| Miranda and Newton (2001) | Case report          | Operating room (Palliative debulking of metastatic tumour at T3 and internal fixation of the thoracic spine); UK | 36 nurses trained in performing advanced life support                   | Simulation with prone positioned mannequin on standard examination coach, with gel-pad under the sternum | 100 midline compressions                                                  | 3376 registered by the skillmeter (91.6% of the total possible), 1168 (34.6%) effective, 1170 (40.6%) partially effective and 838 (24.6%) ineffective |

(continued on next page)
In the event of a cardiac arrest in a prone positioned patient, the clinicians have limited time to decide whether to turn the patient into supine position, before starting CPR, or immediately start a reverse CPR. There is no clear evidence of superiority in terms of effectiveness of reverse compared to supine CPR in patients with cardiac arrest occurring in prone position. Thus, clinicians should take into account several factors when deciding how to start CPR in such cases. Turning the patient into supine position before starting CPR could be very difficult for several reasons: i) this maneuver is time consuming, and can potentially increase the no-flow time to the brain; ii) it may need at least 3–4 operators, not always available in surgical or ICU settings; iii) it could be dangerous for the patients, due to the presence of an open wound, protruding metal work, an unstable spine and fixed head to a Mayfield Skull Clamp potentially causing neurologic injuries, or iv) it could cause the dislodgment of the endotracheal tube and the loss of monitoring. Furthermore, the decision to perform supination and proceed with a standard CPR entails other risks, such as a difficult hemorrhage control (e.g. during spinal surgery) [30]. On the other hand, healthcare personnel might be reluctant to perform reverse CPR as a first option, especially due to the lack of specific training and knowledge of the procedure. Other concerns may regard the presence of an open surgical field, the limited surface to perform compressions, the need for a counterforce under the sternum and the risks of spinal damages. Notwithstanding, cardiac massage in this position is less likely to cause rib fractures, injury to the heart and aspiration pneumonia [9].
turn the patient to the supine position once cardiac arrest has occurred in the prone position, suggesting to start CPR in the prone position [45]. If the aforementioned techniques are not rapidly feasible or become unsuccessful, thoracotomy and direct internal cardiac massage and/or defibrillation are available options [30].

Once a cardiac arrest is detected in a prone-positioned patient, first of all it is important to make sure that airway is secured and the tube is not kinked, obstructed or displaced, in case of intubated patients. Then, it is needed to ensure that the ventilator is connected to the patient with 100% FiO2 concentration and that there is no unidentified loss of blood [12]. If venous air embolism is suspected, the patient’s head should stay down, to increase venous pressure, and the surgical field should be flooded with saline. After that, chest compressions should be started.

Unfortunately, only general indications are provided by the guidelines on how to perform cardiac massage in prone position [46]. Some are provided in AHA recent interim guidance for patients with COVID-19 [7], specifying that “if unable to safely transition the patient to a supine position, place the defibrillator pads in the anterior-posterior position and provide CPR with the patient remaining prone with hands in the standard position over the T7–T10 vertebral bodies”.

Chest compressions can be performed on the posterior thoracic spine at levels between the scapulae, using either a one or two-handed technique, with or without a counterpressure on the sternum. A two-handed technique for chest compressions over the mid-thoracic spine located between the two scapula and the use of a counter-pressure applied by a second person is recommended by Intensive Care Society [47].

ERC provides some other practical indications [43], suggesting compressing between the scapulae (shoulder blades) at the usual depth and rate (5 to 6 cm at 2 compressions per second) and placing defibrillator pad in anterior-posterior (front and back) or bi-axillary (both arms pits) position (Fig. 2). Alternatively, defibrillator pads can be applied in posterolateral position [29], i.e. one pad in the left mid-axillary line and a second one over the right scapula, or over the left scapula (Fig. 2) [19].

A study by Min-Ji Kwon found that in prone position, the largest LV cross-sectional area is located 0 to 2 vertebral segments below the tip of the sternum used as counter pressure and the second one on the thoracic spine, and could be performed by one or two physicians (Fig. 3, panel c) [33].

In the pediatric population cardiac massage can be started in the prone position using the fingers of one hand over the thoracic vertebral column at the level of the scapulae [35] with the same rate and force as they were delivered during supine position.

4.5. Issues related to COVID-19

The COVID-19 pandemic represents a new challenge for clinicians in many fields, including CPR. Among various concerns, the increasing number of prone patients under mechanical ventilation carries along a likely increasing number of cardiac arrests occurring in this position. Hypoxemic respiratory failure secondary to acute respiratory distress syndrome, myocardial injury, ventricular arrhythmias, and shock are common in critically ill patients and put them at high risk of cardiac arrest. Plus, many pharmacological treatments proposed for COVID-19, such as hydroxychloroquine and azithromycin, can prolong the QTs potentially leading to cardiac arrests in high risk patients [49].

A critical point is the risk of viral transmission to healthcare workers during CPR, classified as an aerosol-generating procedure and requiring adequate personal protective equipment [50]. The general principles for resuscitation in COVID-19 patients [7,43] are: i) all the rescuers should wear personal protective equipment (PPE) before beginning CPR; ii) minimize the number of personnel in the room and use a negative-pressure room whenever possible; iii) may use a mechanical device for chest compression if available; iv) use HEPA filter and tight seal for bag-mask ventilation and mechanical ventilation, v) emphasize early intubation performed by the most expert provider, using video laryngoscopy if resources and expertise are available; vi) avoid prolonged resuscitation efforts, since available reports estimate high 30-day mortality rates (97%) in adult COVID-19 patients experiencing cardiac arrest, with low ROSC rates (13%) [51].

All these aspects, together with the issues related to prone position, make the resuscitation of patients with COVID-19 a complex procedure, even for experienced personnel. For all these reasons, healthcare workers need periodical training on manual prone positioning CPR techniques. Simulation training could improve comfort and competence in the procedure and in managing potential complications. To date, no studies have evaluated the efficacy of training for reverse CPR or the use of feedback systems, used to maximize the quality of standard CPR. Furthermore, currently available manikins are not validated for the use in prone position, thus limiting training opportunities. Therefore, there is an urgent requirement for best practice guidance to performing CPR in prone positioned, intubated and non-intubated patients with COVID-19 during the pandemic.

4.6. Future research

Controversial aspects about reverse CPR need to be further investigated with adequately designed studies, to support clinicians with evidence-based indications (e.g. best compressions rate, best thoracic level for compressions, best sternal counterpressure, need for ventilation, decisional algorithm for supination, reverse CPR and thoracotomy with direct cardiac massage). Plus, the preliminary evidence of reverse compressions potentially determining adequate ventilation and tidal volume should be further addressed and has potential implication in other clinical contexts. Healthcare personnel involved in the care of prone positioned patients would also benefit of specific protocols for periodical training on how to perform CPR in a prone patient.

Meanwhile, the available CPR guidelines should be followed.

5. Conclusions

Reverse CPR has been performed and described in several settings, but evidence is based on case reports and preliminary small sized nonrandomized studies. The procedure has been described in settings such as neurosurgery and prone position mechanical ventilation, and an increasing number of cardiac arrests in prone positioned patients is expected in the COVID-19 era. The quality of available evidence is low and knowledge gaps should be fulfilled by further adequately designed
studies that are urgently needed. Meanwhile, a case-by-case evaluation
of patient and setting characteristics should guide the decision on how
to start CPR in such cases.

**Authors’ contribution**

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All the authors approved the final version of the manuscript and agreed to be personally accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Declaration of Competing Interest
None.

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Appendix A. Supplementary data
Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2020.08.097.

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