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Reverse CPR: a pilot study of CPR in the prone position

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Abstract

Background: Cardiopulmonary resuscitation (CPR), as described in 1960, remains the cornerstone of therapy for cardiopulmonary arrest. Recent case reports have described CPR in the prone position. We hypothesized rhythmic back pressure on a patient in the prone position with sternal counter-pressure (termed reverse CPR here) would increase intra-thoracic pressure and in turn systolic blood pressure (SBP) during cardiac arrest versus standard CPR. *Methods and results:* Six patients from Columbia Presbyterian Medical Center's Cardiac and Medical Intensive Care Units (CICU and MICU) were enrolled. Eligible patients had suffered circulatory arrest and failed standard CPR for at least 30 min. After enrollment the patients received 15 additional min of standard CPR and then reverse CPR for 15 min. The study's primary endpoint, mean SBP, significantly improved from 48 mmHg during standard CPR to 72 mmHg during reverse CPR (mean improvement = 23 ± 14 mmHg). Mean calculated mean arterial pressure (MAP) was also improved significantly from 32 mmHg during standard CPR to 46 mmHg during reverse CPR (mean improvement = 14 ± 11 mmHg). The mean diastolic blood pressure (DBP) improved from 24 mmHg during standard to 34 mmHg during reverse CPR (mean improvement = 10 ± 12 mmHg). This difference did not meet statistical significance. No patients had return of spontaneous circulation. *Conclusions:* Reverse CPR generates higher mean SBP and higher mean MAP during circulatory arrest than standard CPR. These novel findings justify further research into this technique.

Keywords: Reverse CPR; Cardiopulmonary resuscitation

Resumo

Contexto: A reanimação cardiopulmonar (RCP), tal como foi descrita em 1960, permanece a base do tratamento da paragem cardio-respiratória (PCR). Alguns relatos recentes descreveram a RCP em pronação. Colocamos a hipótese de a pressão rítmica nas costas do doente em pronação e com contra-pressão esternal (aqui chamada RCP reversa) aumentar a pressão intratorácica e, por conseguinte, a pressão arterial sistólica (PAS) durante a paragem cardíaca quando comparado com a RCP estandardizada. *Método e resultados:* Foram admitidos seis doentes das unidades de cuidados intensivos médicos e cardíacos (CICU e MICU) do Columbia Presbyterian Medical Center. Os doentes elegíveis tinham tido paragem circulatória e tinham tido RCP sem sucesso pelo menos durante 30 minutos. Após selecção, os doentes recebiam mais 15 minutos de RCP standard e depois 15 minutos de RCP reversa. O objectivo primário do estudo, PAS média, melhorou significativamente, passou de 48mmHg durante a RCP standard para 72mmHg durante a RCP reversa (melhora média = 23 ± 14 mmHg). A média calculada da pressão arterial média (PAM) também melhorou significativamente de 32 mmHg durante a RCP standard para 46 mmHg durante a RCP reversa (melhora média = 14 ± 11 mmHg).

Abbreviations: ACD CPR, active compression–decompression cardiopulmonary resuscitation; CICU, cardiac intensive care unit; CPR, cardiopulmonary resuscitation; DBP, diastolic blood pressure; MAP, mean arterial pressure, unit; MICU, medical intensive care; mmHg, millimeters of Mercury, intensive care unit; PEA, pulseless electrical activity; reverse CPR, cardiopulmonary resuscitation in the prone position with sternal counterpressure; SBP, systolic blood pressure.

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A pressão diastólica (PD) média melhorou de 24 mmHg durante RCP standard para 34 mmHg durante RCP reversa (melhora média = 10 ± 12 mmHg). Esta diferença não atingiu significado estatístico. Nenhum doente teve retorno de circulação espontânea. *Conclusões:* A RCP reversa gera maiores PAS e PAM médias durante paragem circulatória que a RCP standard. Estes novos achados justificam que se prossigam as pesquisas relacionada com esta técnica.

Palavras chave: RCP reversa; Ressuscitação cardiopulmonar

Resumen

Antecedentes: La reanimación cardiopulmonar (RCP), como fue descrita en 1960, sigue siendo la piedra angular de la terapia para el paro cardiorespiratorio. Reportes de casos recientes han descrito la RCP en posición prona. Planteamos la hipótesis de que la presión rítmica en la espalda de un paciente en posición prona con contrapresión esternal (aquí llamado RCP invertida) durante el paro cardíaco podría aumentar la presión intratorácica y a su vez la presión sanguínea sistólica (SBP) en comparación con la RCP estándar.*Métodos y resultados*: Se enrolaron 6 pacientes de las unidades de cuidados intensivos cardíacos y médicos (MICU y CICU) del Columbia Presbyterian Medical Center. Los pacientes elegibles habían sufrido un paro circulatorio y fallado la RCP estándar durante por lo menos 30 minutos. Después de ser enrolados los pacientes recibieron otros 15 minutos de RCP estándar y luego 15 minutos de RCP invertida. La meta primaria del estudio, la presión sanguínea sistólica mejoró significativamente de 48 mmHg durante la RCP estándar a 72 mmHg durante RCP invertida (mejoría promedio = 23 ± 14 mmHg). La media calculada de presión arterial media (MAP) también mejoro significativamente de 32 mmHg durante la RCP estándar a 46 mmHg durante la RCP inversa (mejoría media = 14 ± 11 mmHg). La presión sanguínea diastólica (DBP) media mejoró de 24 mmHg durante RCP estándar a 34 mmHg durante la invertida (mejoría media = 10 + 12 mmHg). Esta diferencia no alcanzó significación estadística. Ningún paciente alcanzó retorno a circulación espontánea. *Conclusión*: La RCP invertida genera mas altas Presiones sistólica média y arterial media durante el paro circulatorio que la RCP estándar. Este nuevo hallazgo justifica investigación ulterior acerca de esta técnica.

Palabras clave: RCP invertida; Reanimación cardiopulmonar

1. Introduction

The technique of mechanical cardiopulmonary resuscitation (CPR), as described in 1960, remains relatively unchanged today, with the notable addition of early defibrillation [1,2]. Alternative compression techniques of interposed abdominal counter-pulsation and active compression–decompression (ACD) initially showed promise as technical innovations of standard CPR; however, follow-up studies have been relatively disappointing [3,4]. ACD has been studied multiple times with variable results, but only one study has demonstrated that ACD CPR returns spontaneous circulation sooner and improves survival compared with standard CPR [5]. A recent study of combining abdominal counter-pulsation and ACD CPR for arrested patients failed to demonstrate clear benefit [6]. CPR using a circumferential vest in patients after a prolonged arrest improves return of spontaneous circulation and survival at 24 h, but the need for a mechanical device has limited this technique's implementation [7]. Despite the slow pace of innovation in CPR technique, CPR remains the cornerstone of the initial response to cardiopulmonary arrest, improving the patient's chances of defibrillation and eventual survival [8,9].

E.L. McNeil first described CPR in the prone position as a 'modified Schafer method' in the late 1980s [10]. Based on these ideas and several operative case reports describing prone CPR, we hypothesized that compressions delivered to the posterior thorax in the prone position with a sternal counter-pressure device (termed reverse CPR here) would improve SBP, DBP and, therefore, MAP. In this study we conducted the first pilot feasibility study and also the largest case series of this novel technique, reverse CPR. As a pilot study, we intended to examine the feasibility of reverse CPR in patients beyond hope of recovery.

2. Materials and methods

2.1. Inclusion/exclusion criteria

Subjects for this pilot feasibility study of reverse CPR were prospectively enrolled from Columbia Presbyterian Medical Center's Cardiac and Medical Intensive Care Units (CICU and MICU, respectively) after standard CPR had failed. Failure was defined as at least 30 min of standard CPR without return of spontaneous circulation, and a determination by the responsible physician that further CPR was futile. The patients eligible for the trial included all patients in the CICU and MICU who suffered cardiopulmonary arrest in these units during the day (ca. 07:00–18:00 h). In order to be enrolled patients had to have an arterial line and intravenous catheter in place, their trachea intubated and be age 18

Fig. 1. CPR board—This photo shows the CPR board with a 4.5 kg sandbag on it. During the trial, the sandbag was affixed to the board using surgical tape. The original board was disassembled at the study's completion.

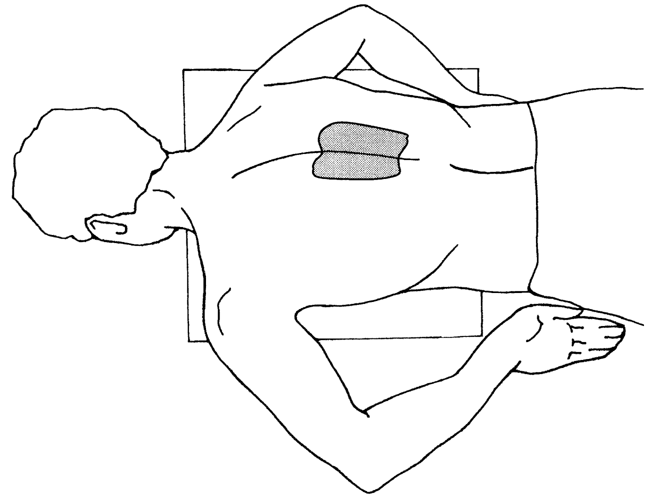

Fig. 2. Patient in prone position—This drawing represents a figure in the prone position on the sternal counter-pulsation device. The shaded area represents where the rescuer would compress during reverse CPR, approximately over the thoracic vertebral bodies numbers 7–10 (artwork by Amanda Deligtisch, MD with permission).

years or older. Patients were excluded from the study if they were pregnant, had a 'do not resuscitate' wish documented, had suffered cardiopulmonary arrest secondary to trauma, had suffered cardiopulmonary arrest secondary to uncontrollable hemorrhage or had undergone a surgical procedure in the last 24 h. The investigators educated physicians working in the CICU and MICU at the beginning of each month on the compression technique used during reverse CPR.

2.2. IRB approval

The combined Presbyterian Hospital-Columbia University institutional review board granted the investigators a waiver of informed consent to enroll patients in this study. Families were notified of the patient's enrollment at the conclusion of CPR.

2.3. Standard CPR/reverse CPR

After at least 30 min of standard CPR and when the physician directing the resuscitation effort determined that standard CPR had failed, the patient was enrolled in the trial. At the time of enrollment, the investigators were present to assist in implementing the study. The arterial line was zeroed to atmospheric pressure for accuracy. Then standard CPR was continued for 15 min without changing the height of the bed. After 15 min, the patient was turned to the prone position and reverse CPR was initiated. Throughout the study's 30-min duration, 1 mg of epinephrine was administered intravenously every 3 min. Cardioversion, ventilation rates and compression rates were used in accordance with Advanced Cardiac Life Saving guidelines. Local ICU practice and the responsible physicians in the two ICUs dictated the choice of pressor agents in each patient. No pressor infusions were initiated or stopped after the patient's enrollment. Mean SBP was defined as the primary endpoint of the study.

Positioning these critically ill patients in the prone position took <1 min. After the period of standard CPR, anterior–posterior defibrillation pads were placed on the patient and attached to the bedside cardiac monitor. Then the investigator at the bedside directed one individual to monitor the central lines and a second individual to place the sternal counter-pressure device under the patient's sternum during positioning. The sternal counter-pressure device consisted of a 4.5 kg sandbag attached to a standard CPR board with surgical tape (Fig. 1). A respiratory therapist unhooked the bag-valve tubing and protected the patient's tracheal tube during positioning. When the patient was in the prone position, the respiratory therapist turned the patient's head to one side, reconnected the bag-valve tubing and resumed ventilation. Care was taken to re-zero the arterial line in the patient's new position to ensure accurate blood pressures before compressions were initiated. In the prone position, compressions were done from the bedside. Both hands were placed in the standard CPR hand position over the T7–10 vertebral bodies (Fig. 2) and compressions were initiated perpendicular to the patient's back at a rate of 60–100 compressions per min.

In five patients continuous blood pressures were recorded using the central monitoring systems of CICU and MICU (Hewlett–Packard Critical Care

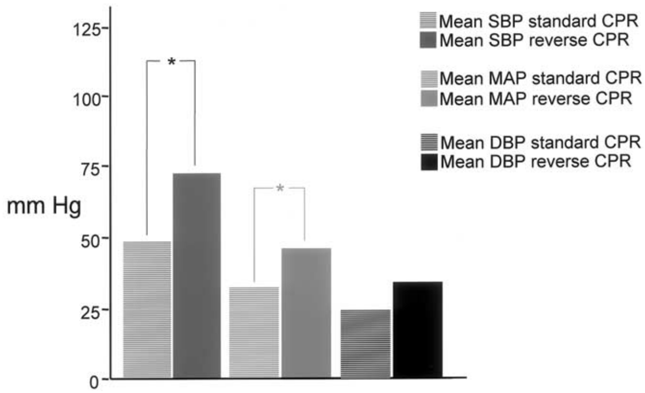

Fig. 3. Mean blood pressure—This bar graph presents the mean SBP, MAP and DBP for all the patients enrolled in the study. The (*) denotes data where the comparison between reverse and standard CPR has a calculated P value <0.05.

Component Monitoring System®). For the first patient, an impartial third party collected data from the bedside monitor. Multiple physicians were involved in each case, because one person could not perform 30 min of CPR. Resuscitators were not blinded to blood pressure.

2.4. Statistics

Both SBP and DBP were recorded, and depending on the ICU monitor's output as many as 15 values were used to obtain mean SBP, DBP and MAP. MAP was calculated for each patient using the formula: MAP = [SBP + 2(DBP)]/3. Paired, two-tailed student's t test was used to compare the differences between blood pressure means. A probability value of less than 0.05 was determined to be a significant result. To estimate a confidence interval for the mean change in blood pressures standard error for 5 degrees of freedom ($n-1$) was calculated. MICROSOFT EXCEL® was used to do statistical calculations.

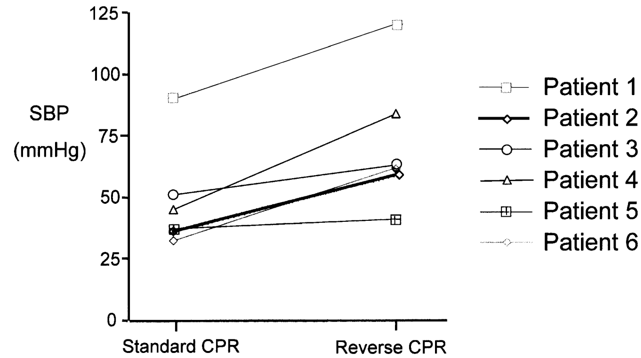

Fig. 4. SBP with reverse CPR and standard CPR—This line graph shows the mean SBP for each patient in the study, illustrating that every patient's SBP improved during reverse CPR.

3. Results

Six patients were enrolled over the course of a year from the CICU ($n=4$) and MICU ($n=2$). They had diverse diagnoses and ages (Table 1). Mean SBP improved from 48 mmHg during standard CPR to 72 mmHg during reverse CPR with a mean improvement of 23±14 mmHg. This difference in the primary endpoint was statistically significant. Mean calculated MAP improved from 32 mmHg during standard CPR to 46 mmHg during reverse CPR with a mean improvement of 14±11 mmHg. This difference was also statistically significant. The mean DBP improved from 24 mmHg during standard CPR to 34 mmHg during reverse CPR with a mean improvement of 10±12 mmHg. This difference did not meet statistical significance (Fig. 3). The mean SBP improved during reverse CPR in six of six patients and the MAP improved during reverse CPR in five of six patients (Figs. 4 and 5, respectively). As expected given the study's design, no patients had return of spontaneous circulation during reverse CPR or survived beyond the study's completion.

Table 1
Patient characteristics

Patient	Sex	Age	Rhythm	First arrest location[a]	Diagnosis[b]
1	Female	51	Vfib[c]	Output MRI	Restrictive cardiomyopathy
2	Male	54	PEA	Floor	Sepsis
3	Male	61	Vtach[d]	ED	AMI[e]
4	Male	57	PEA	Floor	Tumor lysis/Acidosis
5	Male	30	PEA	Floor	ARDS[f]/sepsis
6	Female	70	PEA	Floor	Unknown

[a] First arrest location refers to the site where these patients first suffered circulatory arrest.
[b] Diagnosis was assigned to the patient based on a review of the chart at the time of death.
[c] Vfib, ventricular fibrillation.
[d] Vtach, ventricular tachycardia.
[e] AMI, acute myocardial infarction.
[f] ARDS, adult respiratory distress syndrome.

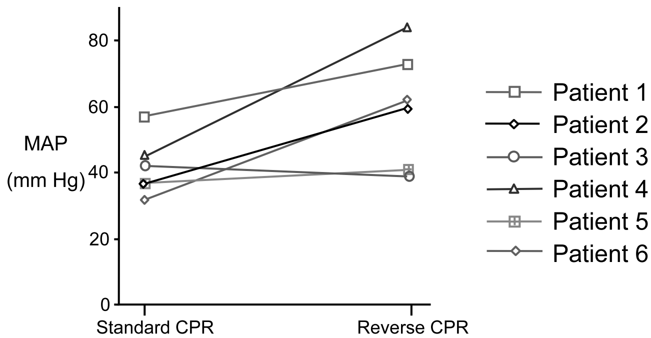

Fig. 5. MAP with reverse CPR and standard CPR: the line graph shows the mean MAP for each patient in the study, illustrating that 5 of 6 patients had improved in their MAP during reverse CPR.

Patient 3 had brief return of spontaneous circulation (~ 1 min) during the standard CPR period. Data from this minute was excluded from the final analysis.

4. Discussion

This study represents the first pilot feasibility study and largest case series of reverse CPR. In these ICU patients, reverse CPR significantly improved the primary endpoint of mean SBP. The secondary endpoint MAP was also significantly improved. In addition, mean DBP demonstrated a trend towards improvement, increasing in five of six patients, some dramatically. This first prospective feasibility study of reverse CPR corroborates the operative case reports of CPR in the prone position. The first case report described two cases of successful intra-operative resuscitation of two patients who had suffered circulatory arrest while in the prone position [11]. Subsequently, several more operative case reports of patients receiving CPR in the prone position have been published [12–15]. In each case, a patient undergoing an operation in the prone position suffered circulatory arrest and received CPR in the prone position. These patients all maintained near physiologic blood pressures during CPR in the prone position and survived to discharge neurologically intact.

The difficulty of CPR research required this pilot feasibility study to occur in the ICU setting after standard CPR had failed. These patients are not ideal candidates, as their very low blood pressures during standard CPR demonstrate. Patients who have failed standard CPR are the most physiologically deranged patients, suffering profound vasodilation from multiple etiologies and persistent intravascular depletion. These factors tend to worsen with each minute of prolonged circulatory arrest. This study's crossover design handicapped its ability to detect improvement in SBP with reverse CPR and prevented examining its effect on survival. Despite this handicap and prolonged circulatory arrest (greater than 45 min in all patients), reverse CPR dramatically improved SBP and MAP.

Two previously proposed models seem to explain the observation that sternal compressions produce an arterial pressure waveform during circulatory arrest. The first model (the cardiac-pump model) postulates that sternal compression compresses the right and left ventricles. This compression is thought to eject blood into the pulmonary circulation and aorta, respectively, creating forward blood flow [16]. The second model (the thoracic-pump model) postulates that sternal compression decreases intra-thoracic volume, increasing intra-thoracic pressure. In the extra-thoracic veins, competent venous valves prevent backward venous blood flow. The combination of venous valves and increased intra-thoracic pressure is thought to create a pressure gradient between the intra- and extra-thoracic venous systems favoring anterograde blood flow. Similarly, in the proximal aorta, the aortic valve and increased intra-thoracic pressure create a pressure gradient between the intra- and extra-thoracic portions of the carotid arteries favoring anterograde flow [16]. Transesophageal echocardiography of the thoracic aorta during standard CPR has provided direct evidence that probably both postulated mechanisms work in concert to generate forward blood flow [17].

Using these models as a basis for understanding these results, we have hypothesized that reverse CPR could improve systolic (and therefore, diastolic) blood pressure in two distinct ways. First, the more rigid thoracic costo-vertebral joints should allow more forceful compressions than the easily damaged sternal costo-chondral junctions. Increased force should generate higher pressures in the intra-thoracic venous and arterial conduits (thoracic-pump) and the compressed ventricles (cardiac-pump) improving forward flow. We chose not to control the force of compressions, because we felt this was an important aspect of reverse CPR's potential benefit.

Second, reverse CPR should correct an important mechanical inefficiency of standard CPR. In the supine position each anterior sternal compression forces the diaphragm inferiorly, displacing the abdominal structures anteriorly, dissipating the compression's force. Prone positioning places the abdomen in contact with a firm surface, restricting the movement of the abdominal structures and should, therefore, enhance the compression's efficiency.

The sternal compression device was added to the technique based on the observation in case reports that sternal counterpressure was necessary. With the raised sandbag directly under the sternum, each posterior compression should depress the sternum more efficiently transducing the force to the ventricles (cardiac-pump) and increasing the rapid reduction in intra-thoracic volume (thoracic-pump).

4.1. Study limitations

This study was designed to assess only the feasibility of reverse CPR as a technique. It must be emphasized that this study did not aim to determine the effects of reverse CPR on return of spontaneous circulation or survival. The inability to blind the person doing compressions to blood pressure is a difficult feature of this type of research and may introduce bias. While we recognize the possibility that bias may explain our results, our impression is that the blood pressures during standard supine CPR remained approximately the same before and after enrollment. In addition multiple physicians did compressions as part of the study, and we attempted to have them perform CPR in both positions when possible. The crossover study design also was designed to handicap reverse CPR as much as possible; all of these patients had received standard CPR for at least 45 min before beginning reverse CPR.

In the prone position several aspects of care are more difficult to perform including neurologic assessment, central venous and arterial access, physical examination and tracheal tube insertion and maintenance. This study was not designed to examine the effect of prone position on these features of care.

The monitoring and therapeutic tools of the ICU hindered prone positioning and presented a significant obstacle to reverse CPR's implementation in the ICU. Despite these limitations, in this study, each patient was turned from the supine to prone position by only three to four people in less than 1 min. We believe in a different patient care setting prone positioning would be equivalent to the positioning now required to deliver standard CPR.

Recent CPR trials have cast doubt on the value of positive pressure ventilation during bystander resuscitation efforts. Comparison of bystander CPR with and without mouth-to-mouth resuscitation demonstrated no improvement in survival with ventilation, and animal studies have suggested ventilatory pauses may actually worsen neurological outcome [18,19]. This change may widen reverse CPR's potential application in the future. In the unconscious, unintubated patient, prone positioning CPR may also improve airway patency. The prone position used in reverse CPR may assist in gas exchange as it does in other patients, such as patients with acute lung injury [20]. Further research should include examination of reverse CPR's effects on gas exchange and the mechanism of its improvement of blood pressure.

5. Conclusion

This is the first study to crossover patients from standard CPR to a novel CPR technique after standard CPR has failed in an ICU setting. This pilot feasibility study adds credence to already published case reports of patients resuscitated intra-operatively in the prone position.

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The nursing staff, residents and attending physicians of the CICU and MICU, who participated in each of these cases deserve recognition for their dedication and their essential contribution to this study.

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