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Review article

Interposed abdominal compression CPR: a comprehensive evidence based review

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Abstract

Interposed abdominal compression (IAC)-CPR includes all steps of standard external CPR with the addition of manual mid-abdominal compressions in counterpoint to the rhythm of chest compressions. IAC-CPR can increase blood flow during CPR about 2-fold compared with standard CPR without IAC, as shown by six of six studies in computer models and 19 of 20 studies in various animal models. The addition of IAC has clinical benefit in humans, as indicated in 10 of 12 small to medium sized clinical studies. The technique increases the frequency of immediate return of spontaneous circulation for in-hospital resuscitations from roughly 25 to 50%. Improved survival to discharge is also likely on the basis of two small in-hospital trials. Possible harm from abdominal compression is minimal on the basis of 426 humans, 151 dogs and 14 pigs that received IAC in published reports. The complexity of performing IAC is similar to that of opening the airway and is less than that of other basic life support maneuvers. The aggregate evidence suggests that IAC-CPR is a safe and effective means to increase organ perfusion and survival, when performed by professionally trained responders in a hospital and when initiated early in the resuscitation protocol. Cost and logistical considerations discourage use of IAC-CPR outside of hospitals.

Keywords: Abdomen; Clinical trials; Guidelines; Interposed abdominal compression-CPR; IAC-CPR; Review; Statistical analysis

Resumo

A reanimação com compressão abdominal interposta (IAC-CPR) inclui todos os passos da CPR externa standard com adição de compressões médio-abdominais em contraponto com o ritmo das compressões torácicas. A IAC-CPR pode aumentar cerca de duas vezes o fluxo sanguíneo em comparação com CPR standard sem IAC, tal como foi demonstrado por 6 de 6 estudos em modelos de computador e 19 de 20 estudos em vários modelos animais. A adição de IAC tem benefício clínico em humanos, conforme indicado por 10 de 12 estudos clínicos de pequena a média dimensão. A técnica aumenta a frequência de retorno a circulação espontânea na reanimação intra-hospitalar de 25 para 50%. É igualmente provável uma melhoria da sobrevida até à alta com base em 2 pequenos ensaios hospitalares. O possível dano provocado pela compressão abdominal é mínimo com base em 426 estudos humanos, 151 em cães e 14 em porcos que receberam IAC. A complexidade da realização de IAC é semelhante à da permeabilização da via aérea e é menor do que a de outras manobras de suporte básico de vida. A evidência agregada sugere que a IAC-CPR é um modo seguro e eficaz de aumentar a perfusão de órgãos e a sobrevida, quando executada num hospital por profissionais treinados e quando iniciada precocemente no protocolo de reanimação. Considerações logísticas e de custos desaconselham o uso de IAC-CPR fora dos hospitais.

Palavras chave: Abdómen; Ensaios clínicos; Recomendações; Compressões abdominais interpostas-CPR; IAC-CPR; Revisão; Análise estatística.

Resumen

La reanimación cardiopulmonar(CPR) con compresión abdominal interpuesta (IAC) incluye todos los pasos de la CPR externa estándar a la que se le agrega la compresión manual medio abdominal en contrapunto con el ritmo de las compresiones torácicas. La

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IAC-CPR puede aumentar el flujo sanguíneo durante la reanimación cerca de dos veces comparada con la CPR estándar sin IAC, como ha sido demostrado por seis de los seis estudios en modelo computacional y en 19 de 20 estudios en varios modelos animales. El agregar la IAC tiene beneficios clínicos en humanos, como es indicado en 10 de 12 estudios clínicos pequeños y de mediano tamaño. La técnica aumenta la frecuencia de retorno a circulación espontánea en resucitación intra hospitalaria de 25 a 50%. La mejoría en la sobrevida al alta es también probable sobre la base de dos pequeños estudios intrahospitalarios. La probabilidad de daño por las compresiones abdominales es mínima sobre la base de 426 humanos, 151 perros y 14 cerdos que recibieron IAC en reportes publicados. La dificultad para realizar IAC es similar a la de despejar la vía aérea y es menor que otras maniobras de soporte vital básico. La evidencia agregada sugiere que la IAC-CPR es un medio seguro y efectivo de aumentar la perfusión y sobrevida de órganos, cuando es realizada por reanimadores profesionales entrenados de un hospital y cuando es iniciado tempranamente en el protocolo de resucitación. Consideraciones acerca del costo y la logística desaconsejan el uso de IAC-CPR fuera de los hospitales.

Palabras clave: Abdomen; Ensayos clínicos; Guías clínicas; RCP compresión abdominal interpuesta; RCP de CAI; Revisión; Análisis estadístico.

1. Introduction

Interposed abdominal compression (IAC)-CPR includes all the steps of ordinary CPR with the addition of external mid-abdominal compressions by a second or third rescuer, timed between chest compressions. The abdominal compressions are delivered in counterpoint to the rhythm of chest compressions, so that abdominal pressure is maintained whenever the chest is not being compressed. Pulses of central abdominal pressure are applied with overlapping hands just cranial to the umbilicus. Hand position, depth, rhythm, and rate of abdominal compression are similar to those for chest compression. The force of abdominal compression is similar to that needed to palpate the abdominal aortic pulse. The technique of IAC-CPR achieved some notoriety in the 1990s after the clinical studies by Sack and coworkers, involving several hundred patients, suggested an approximate doubling of immediate resuscitation success and neurologically intact, long-term survival [1].

The present paper is an extensive evidence based review. Relevant full length, peer reviewed publications were identified using evidence evaluation methods described previously [2,3] and developed specifically for topics in emergency cardiovascular care. Full-length, peer reviewed publications were obtained from MEDLINE searches, the author's files, and reference lists of review articles on newer techniques in resuscitation as referenced in "Guidelines 2000 for CPR and emergency cardiovascular care: international consensus on science" [4].

The results of the search turned up a rather remarkable accumulation of positive evidence published since 1980, documenting the hemodynamic and clinical benefits of IAC-CPR, when compared with conventional standard CPR in a variety of pre-clinical and clinical models (Table 1). Despite the relatively small numbers of patients reported in human clinical trials, the overall tone of this review is, therefore, positive and rather different from that of the usual conservative review of controversial topics in science: "John found this, but Mary found the opposite. More research is needed". Of the 38 full-length, peer reviewed studies (Table 2) relevant to IAC-CPR, 34 obtained results indicating benefit of IAC. Two found no difference between IAC and standard CPR, and two found results worse for IAC than for standard CPR. Only a single case report describes an adverse complication attributable to external abdominal compression—possible traumatic pancreatitis in a child. Even the authors of this report stated that their finding was "not meant to condemn a technique which may ultimately prove superior to conventional CPR" [5].

Why has IAC-CPR not been enthusiastically adopted already for widespread clinical use? Why is the method only recommenced in current guidelines as an optional alternative technique rather than standard of care? Probably in part because nearly all of the 38 studies were small, and inexpensive affairs, often conducted by researchers fundamentally interested in other research topics or who came upon the phenomenon of IAC by accident. Moreover, as is typical in the field of CPR, there is a paucity of human data. Large multi-center clinical trials were never conducted. Moreover, in the United States changed federal regulations in the 1990s, making clinical studies of resuscitation exceedingly difficult with respect to informed consent, were promulgated just as clinical evidence favoring IAC started to accumulate [6,7].

The technique of IAC-CPR is analogous to an orphan drug. No device or product is needed to perform IAC, and so there is no multi-national corporation to fund or support relevant research and development. Appreciation of the science supporting abdominal compression as an adjunct to chest compression requires the aggregation and synthesis of scattered studies published in diverse journals by investigators from nine countries in 11 different sub-specialties of science and medicine (Tables 2 and 3). Such a comprehensive review has not been published heretofore.

Table 1
Broad summary of research on IAC-CPR in three classes of experimental models

Model class	Subtypes	Results
Mathematical, computer and mechanical models	Paper and pencil [22]	Six of six studies positive (100%)
	Analog [17,19]	
	Digital [18,20]	
	Digital spreadsheet [21]	
Animal models (dogs and pigs)	Blood flow [14–16,27–29,53–55]	19 of 20 studies positive (95%)
	Blood pressure [10,11,23,56]	
	Oxygen uptake [26]	
	CO_2 excretion/blood gasses [57]	
	Survival and complications [25,30,31,43,58]	
Clinical models	Pediatric anesthesia overdose [9]	10 of 12 studies positive (83 %)
	Acute hemodynamics (BP, $ETCO_2$ ±crossover) [32–34,46,59–61]	
	All arrests (mostly VF) [1,45]	
	Difficult arrests (EMD, asystole, prolonged) [35,36]	

For most end points results for IAC-CPR were between 1.5 and 2.0 times those for comparable standard CPR without abdominal compression. EMD, electromechanical dissociation; $ETCO_2$, end tidal carbon dioxide concentration; VF, ventricular fibrillation.

Table 2
Data base composition by level of evidence[a]

Level	Capsule description of level	# of papers
1	Larger randomized clinical trials [1,36,45]	3
2	Smaller randomized clinical trials [34]	1
3	Prospective, non-randomized cohort studies [33,62]	2
4	Historic, non-randomized cohort studies [9,59,63]	3
5	Human case series [39,60,61]	3
6	Animal or mechanical model studies [10,11,14–23,25–31,43,53–58]	25
7	Rational extrapolations or quasi-experimental designs [64]	1
8	Common sense, etc.	0

[a] Performance sites for reviewed studies included USA 28 studies, UK 2, Israel 2, Canada 2, Japan 1, Germany 1, Netherlands 1, Spain 1, and Italy 1 (some studies had multiple sites).

Table 3
Departmental affiliations of investigators publishing on IAC-CPR

Anesthesiology	27
Biomedical Engineering	10
Cardiology	3
Critical care	2
Emergency Medicine	8
Industry	1
Internal Medicine	7
Neurobiology	1
Physiology	6
Radiology	1
Surgery	6

2. Early work on abdominal counterpulsation

Three years before external CPR was described by Kouwenhoven, Jude and Knickerbocker in 1960 [8], Rainer and Bullough in the United Kingdom developed a jackknife maneuver for resuscitation of children from anesthetic overdose, which involved rhythmically compressing first the abdomen and then the chest [9]. The technique required the surgeon to fold the knees of a child as far as possible toward the chin, forcing the thighs against the abdomen. Then "when full flexion is reached, the surgeon compresses the patient's chest with the bent knees, using some of his own weight judiciously to add to the pressure" [9]. This method can be regarded as a version of phased abdominal and chest compression and was successful in eight of eight reported cases.

In 1972 Molokhia, Norman and coworkers at Boston City Hospital [10] described a similar means of generating an artificial circulation during open chest surgery by alternately compressing the aortic arch and the left ventricle. The addition of interposed aortic compressions augmented coronary pertusion by about 50%. In 1976 Ohomoto [11] at Tokyo Women's medical college resuscitated anesthetized dogs with two motor driven pistons, one compressing the abdomen, the other the chest. The addition of phased abdominal compression for 80% of cycle time to chest compression for 25% of cycle time increased carotid artery blood pressure and improved short-term survival in anesthetized dogs with ventricular fibrillation.

Subsequently Rosborough and coworkers in Houston Texas [12] while attempting to develop an animal model of cough CPR [13] combined simultaneous high-pressure lung inflation with abdominal compression. They found to their surprise that abdominal compression and ventilation alone could maintain carotid flow and aortic pressure during ventricular fibrillation in dogs. They suggested the technique as a new CPR modality. Contemporaneously, Coletti, Bregman and coworkers in New York were studying a canine model of cardiogenic shock in the laboratory one day, when the mechanical intra-aortic balloon pump failed to work properly [14]. As a substitute they tried manual external abdominal compressions interposed between heartbeats, as judged from the electrocardiogram. Both cerebral and coronary perfusion, measured with electromagnetic flowmeters, increased.

Ralston et al. [15] described the modern idea of alternating compression of the abdomen and the chest for the purpose of external CPR in the year 1982. The first graphic record demonstrating the phenomenon is reproduced in [16]. Subsequently a burst of preclinical studies, followed by clinical studies, appeared in the 1980s and 1990s. These included a wide variety of model systems and experimental end points (Table 1).

The following summary of evidence is organized according to the ‘‘Levels of Evidence’’ paradigm for topics in resuscitation research, which is described in detail in [3]. Research reports are assigned to a particular level according to the study design and methodology. Level 1 studies are considered the most relevant to human medicine, providing the strongest evidence favoring a novel intervention. Level 2 studies are the next most relevant, etc. continuing to Level 8 reports, which are speculative opinion pieces without actual data. Table 2 gives an overview of reviewed studies in terms of their levels of evidence, together with brief definitions of the levels.

3. Mechanical, electrical, and computer models (Level 6)

A number of investigators with a biomedical engineering bent have investigated IAC-CPR by building mechanical, electrical, or computer models [17–22]. A good example of this genre is provided by the electrical model of Ralston and Babbs [17], who appreciated the analogy between the flow of current around an electrical circuit and the circulation of blood through systemic and pulmonary vessels. In their simulations electrical resistance mimicked physiological resistance of vascular beds. Resistive–capacitive networks modeled the heart and blood vessels. Voltages represented intravascular pressures; electric current represented blood flow, inductance modeled blood inertia, and diodes served as the cardiac and venous valves. The application of half-sinusoidal voltage pulses to the model represented the effects of compression of the chest and abdomen during CPR. In this model the addition of IAC to standard CPR produced flow augmentation according to the expression:

$$\text{flow} = \alpha P_{th} + \beta P_{abd},$$

where P_{th} is the peak intrathoracic pressure; P_{abd}, the peak intraabdominal pressure; and α and β are constants ($\alpha > \beta$). For typical adult CPR intra-abdominal pressure can be made somewhat greater than intrathoracic pressure ($P_{abd} > P_{th}$), so that chest and abdominal flow components become roughly equal. Thus the addition of IAC doubled flow in this electrical model of the adult human.

Such theoretical models also provided a detailed glimpse into hemodynamic mechanisms of abdominal counterpulsation. Fig. 1 shows simulated pressure waveforms in a more recent model of a typical adult human circulation [21] during standard and IAC-CPR. Two mechanisms are evident upon close inspection. The first is the obvious hump in aortic blood pressure (squares) during the abdominal compression phase, which is greater than the corresponding rise in central venous pressure (circles). The second, and subtler, mechanism is the augmentation of the filling phase of the chest pump (i.e. pulmonary vasculature), represented by the positive difference between right heart and chest pump pressure (Prh-Ppump) during the last one fifth of the compression cycle. Thus external abdominal compression acts like an intra-aortic balloon pump, to squeeze more blood from the aorta into systemic resistance vessels. It also acts to squeeze more venous blood into the chest pump, priming it before the next chest compression. In this way phased abdominal pressure has beneficial effects upon both the arterial and the venous sides of the circulation.

4. Animal studies (Level 6)

The prediction of such theoretical models that IAC could nearly double blood flow during CPR turned out to be quite congruent with results of animal studies, which are also considered as Level 6 evidence. Much of the research comparing interposed abdominal compression CPR with standard CPR has been done in animal models—typically anesthetized pigs and anesthetized dogs with electrically induced ventricular fibrillation. Generally such models, summarized in Table 1, have found indices of blood flow during CPR to increase by 50–100% with the addition of IAC to the resuscitation protocol. Examples include increased carotid artery flow [11,23–25], regional blood flow [26–29], systemic and coronary perfusion pressures [15,26,29,30], cardiac output [26], and oxygen delivery [26].

Animal studies have also tracked resuscitation success and survival. Kern’s initial study of groups of ten animals showed no significant difference in immediate resuscitation success or 24 h survival [31]. However, Lindner et al. [30], using groups of 14 ketamine anesthetized pigs, found return of spontaneous circulation in 0/14 animals with standard CPR versus 14/14 with IAC-CPR. Tang [25], using the Lifestick device that permitted one rescuer to do alternating chest and

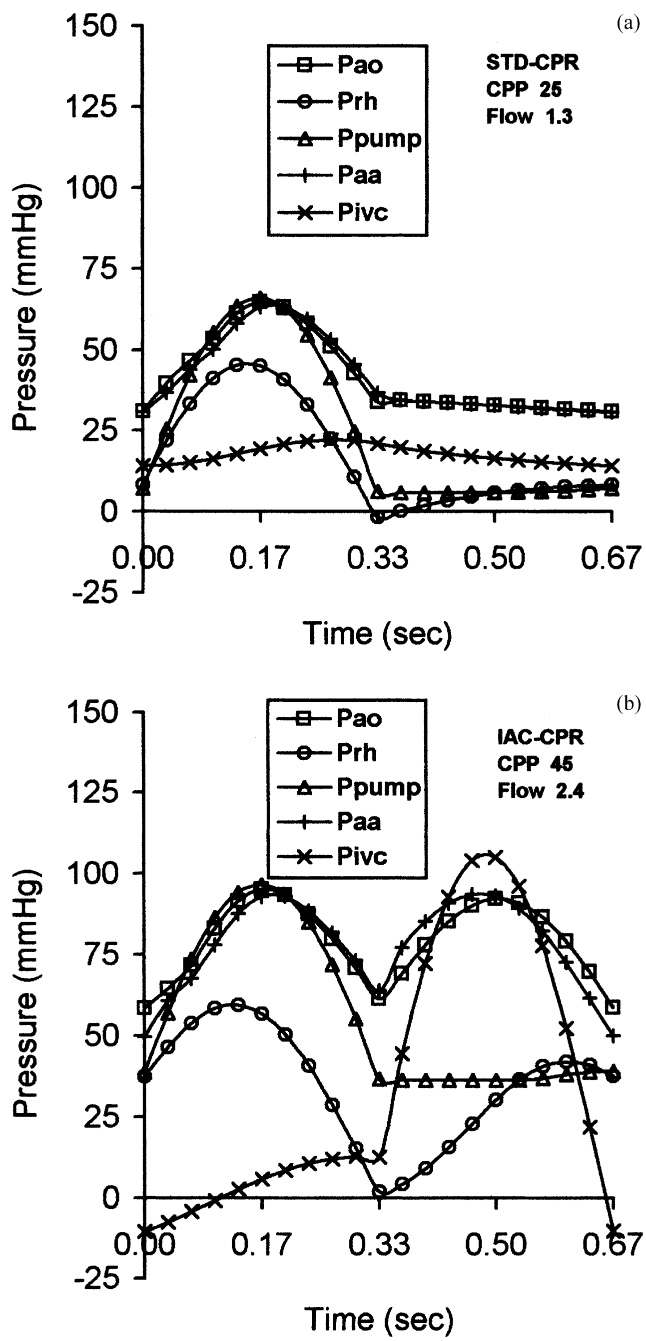

Fig. 1. Simulated pressure waveforms during standard and IAC-CPR in a typical adult. Steady state pressures after 20 compression cycles are shown. Peak applied pressures: chest 60 mmHg, abdomen 110 mmHg. Compression rate 90 per min. (a) Standard CPR. (b) IAC-PCR. Ao, thoracic aorta; rh, right heart; pump, thoracic pump (pulmonary arteries and veins); aa, abdominal aorta; ivc, inferior vena cava. CPP is coronary perfusion pressure in mmHg. Flow is total systemic blood flow in l/min. Data redrawn from [21].

abdominal compression, obtained similar positive results in pigs—10/10 versus 0/10 survival at 48-h for chest compression plus IAC versus chest compression alone.

5. Preliminary clinical studies (Levels 3–5)

Preliminary human studies, short of randomized clinical trials, provided further evidence for hemodynamic effects of external abdominal compressions. Howard et al. [32] instrumented 14 patients in the emergency department for blood pressure measurements during alternate trials of standard versus IAC-CPR. They found that IAC and high force IAC increased diastolic and mean arterial pressures, but not necessarily arteriovenous pressure differences, and that the effects of IAC were greater in non-obese patients. Adams [33] studied hemodynamics of IAC during human CPR in patients that were unsalvageable by conventional ACLS. There were 13 responders with a mean change in coronary perfusion pressure of 9.5 mmHg and seven non-responders with a mean change in coronary perfusion pressure of −2.6 mmHg. Berryman and Phillips [34] also studied IAC-CPR in six cardiac arrest patients after unsuccessful ACLS. Mean arterial pressure increased from 26 to 39 mmHg. Villa, Colombo and coworkers [35] reported one case of a successful 1 h and 20 min long resuscitation of a patient with pulseless electrical activity using a combination of mechanical chest compression and manual IAC. The patient lived subsequently for 8 h following cardiac arrest and resuscitation.

6. Randomized clinical trials (Levels 1–2)

6.1. *Efficacy of IAC-CPR*

Three randomized clinical trials of IAC-CPR for in-hospital cardiac arrest have shown statistically significant improvement of outcome measures [1,36,46]. One randomized trial of pre-hospital IAC-CPR, combined when possible with standard CPR in the field, showed no difference in outcome or in complications [37]. These clinical trials are summarized in Table 4. Pooled analysis of all available data for both pre-hospital and in-hospital resuscitations shows improvement in the return of spontaneous circulation with IAC-CPR, compared with standard CPR (Table 5). When only the in-hospital studies are examined, the effect of IAC becomes much greater. Pooled data from the two studies that examined long term, neurologically intact survival following in-hospital resuscitations show a similar relative benefit of IAC-CPR compared with standard CPR. A formal meta-analysis of statistical significance is presented in Section 6.3.

6.2. *Complications of IAC-CPR*

The safety of interposed abdominal compressions, reviewed previously [38], has been well documented in

Table 4
Summary of randomized clinical trials of IAC vs. standard CPR

Lead author	Year	*n*	Results
Mateer [37]	1985	291	40/145 (28%) resuscitated with pre-hospital protocol involving STD-CPR, paramedic IAC-CPR, then STD-CPR during transport. 45/146 (31%) resuscitated with STD-CPR throughout the pre-hospital phase. No evidence of abdominal injury
Ward [46]	1989	33	6/16 (37%) resuscitated in the emergency department with initial 20 min of IAC-CPR vs. 3/17 (18%) with STD-CPR. End Tidal CO_2 averaged 17.1 mmHg with IAC-CPR vs. 9.6 mmHg with STD-CPR, indicating improved blood flow. No evidence of abdominal injury
Sack #1 [1]	1992	103	29/48 (60%) resuscitated from in-hospital cardiac arrest with IAC-CPR vs. 14/55 (25%) with STD-CPR. Survival to discharge was 12/48 (25%) for IAC-CPR vs. 4/55 (7%) for STD-CPR. No evidence of abdominal injury from IAC
Sack #2 [36]	1992	143	33/67 (49%) resuscitated from in-hospital asystole or EMD with IAC-CPR vs. 21/76 (28%) with STD-CPR. No long term survivors. No evidence of abdominal trauma from IAC

IAC, interposed abdominal compression; STD, standard; EMD, electromechanical dissociation (pulseless electrical activity of the heart).

426 humans, 151 dogs and 14 pigs. Only one isolated case report of traumatic pancreatitis in a child [39] describes local trauma from abdominal compression during CPR. These data compare favorably with the well-known and frequent incidence of rib fracture and pulmonary contusion from chest compression during CPR [40–42]. Increased emesis and aspiration from IAC have not been reported, and there is evidence that if positive abdominal pressure is applied during ventilations from the beginning of an arrest, the rate of gastric inflation before tracheal intubation is reduced [43].

6.3. Meta-analysis

A more rigorous meta-analysis of IAC-CPR has recently been published [44] that is limited to human clinical trials in which the end point was either short term or long term survival. These include all available survival data from the three in-hospital trials and one and out-of-hospital trial [1,36,45,46]. Hemodynamic data were not considered. Meta-analysis refers to the quantitative synthesis of data from multiple clinical studies in order to minimize both Type I and II statistical errors. Inverse variance weighting of outcome data is typically used to account for the relative numbers of patients in the various studies. Results for such an analysis of IAC-CPR trials are shown in Fig. 2. This figure shows cumulative meta-analysis plots that demonstrate historical trends with the publication of each successive clinical study. In each plot the top data point and its 95% confidence interval represent the historically first trial, the next a combination of the first two trials, the third a combination of the first three trials, etc. This format is similar to that introduced by Lau and coworkers [47] for cumulative meta-analysis in cardiovascular medicine.

The combined studies of IAC-CPR, including all available in-hospital and out-of-hospital data (Fig. 2(A)), showed a significant treatment effect for short-term and probably for long-term survival. The difference in the proportion of survivors, $\overline{\Delta p}$, is 10.7% for return of spontaneous circulation and 8.7% for hospital

Table 5
Aggregate human ROSC and survival data for IAC vs. standard CPR

Outcome measure	Studies	IAC-CPR	Standard CPR
Return of spontaneous circulation (ROSC) in or out-of-hospital	Mateer [37]	40/145 (28%)	45/146 (31%)
	Ward [46]	6/16 (38%)	3/17 (18%)
	Sack #l [1]	29/48 (60%)	14/55 (25%)
	Sack #2 [36]	33/67 (49%)	21/76 (28%)
	All four studies	108/276 (39%)	83/294 (28%)
Return of spontaneous circulation (ROSC) after in-hospital resuscitation	Ward [46]	6/16 (38%)	3/17 (18%)
	Sack #l [1]	29/48 (60%)	14/55 (25%)
	Sack #2 [36]	33/67 (49%)	21/76 (28%)
	All three studies	68/131 (52%)	38/148 (26%)
Survival to discharge, neurologically intact after in-hospital resuscitation	Ward [46]	1/16 (6%)	0/17 (0%)
	Sack #l [1]	8/48 (17%)	3/55 (5%)
	Both studies	9/64 (14%)	3/72 (4%)

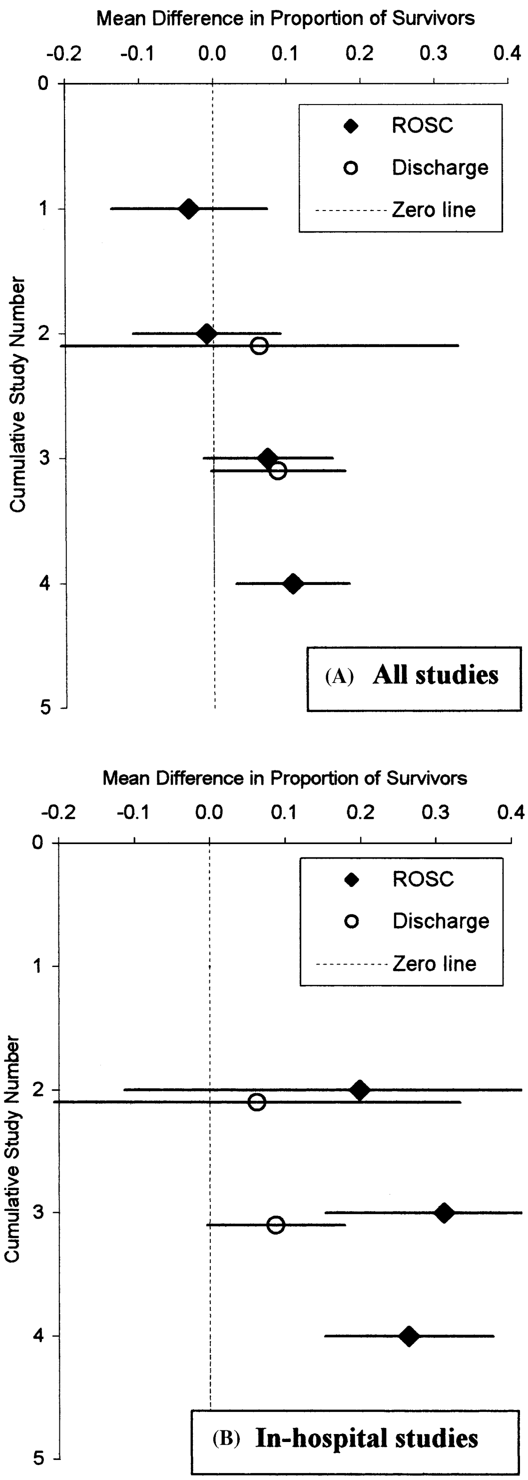

Fig. 2. A cumulative meta-analysis for IAC-CPR in terms of the mean difference in proportion of survivors (IAC minus Standard CPR) [44]. Successive points from top to bottom represent a separate meta-analysis after the appearance of each study [1,36,37,46] in the series. Solid symbols refer to data for return of spontaneous circulation (ROSC), open symbols to data for neurologically intact discharge survival. Horizontal lines indicate 95% confidence intervals. (A) All studies in which survival was measured, including one out-of-hospital and three in-hospital studies. (B) In-hospital studies only [1,36,46].

discharge. The effect of IAC in the overall meta-analysis is highly significant for return of spontaneous circulation ($P = 0.006$) and of borderline statistical significance ($P = 0.06$) for discharge survival. These summary values can be immediately converted into the number-needed-to-treat, $\mathrm{NNT} = 1/\overline{\Delta \mathrm{p}}$, the number of patients that must be treated to obtain one additional survivor [48]. For return of spontaneous circulation the NNT is 9. For discharge survival the corresponding NNT is 12. When only in-hospital studies are considered (Fig. 2(B)) the statistical significance of the meta-analysis for return of spontaneous circulation is even greater ($P < 0.0001$, $\mathrm{NNT} = 4$).

7. Implementation issues

Practical implementation of a new method requires consideration of issues other than simply efficacy and safety. If a technique is extremely costly, difficult to teach or to learn, or likely only to benefit a small number of patients (with a large number-needed-to-treat) then it may not be suitable for widespread clinical implementation. Since IAC requires no new equipment or drug, its added cost is minimal, as long as adequate personnel are available in the hospital setting. However, as initially discovered by Mateer and coworkers [45], lack of trained personnel in out-of-hospital settings can obviate the use of IAC-CPR. Short reviews of the issues of complexity, cost versus benefit, and pedagogy are as follows.

7.1. Complexity

Making resuscitation efforts more complicated, especially for lay rescuers, is a tricky business. More complicated techniques may be less effective in practice, if the added complexity is difficult to learn and easily forgotten [49,50]. The limitation of IAC-CPR to trained health care providers is one way to minimize problems in this area. Fortunately, the technique of interposed abdominal compression itself is much less complicated than most steps of basic life support for either lay or professional rescuers (notably the recovery position, the Heimlich maneuver, and AED use). A detailed analysis of the complexity of the maneuver compared with other steps of basic life support is provided in Tables 6 and 7. Abdominal compression is clearly no more difficult than chest compression and arguably easier, since rescuers already know chest compression, and there is no varying chest wall stiffness to overcome in the abdomen.

7.2. Cost versus benefit

Suppose that IAC-CPR were implemented for in-hospital resuscitations only. How many more long term

Table 6
Summary of complexity analysis of various basic life support manoeuvers done by lay or professional rescuers

Basic life support maneuver	Number of steps	Number of branches	Steps × branches product
Dealing with choking	7	4	28
Using an AED	5	5	25
Placing victim in recovery position	9	2	18
Starting rescue breathing	4	3	12
Starting chest compressions	6	1	6
Opening an airway	2	2	4
Doing IAC	2	2	4

survivors ($\Delta N_{survivors}$) of cardiac arrest might be expected? One simple calculation can be done as follows:

$$\Delta N_{survivors} = N_{arrests} \cdot P_{in\text{-}hosp} \cdot \Delta P_{rosc} \cdot P_{long\ \ term},$$

where, $N_{arrests}$ is the number of cardiac arrests in nation per year; $P_{in\text{-}hosp}$, the proportion of in-hospital resuscitations; ΔP_{rosc}, the change in proportion of ROSC attributable to IAC; and $P_{long\ term}$ is the proportion of initial saves who walk out of the hospital.

The research reviewed herein indicates that ΔP_{rosc} is 22% for in-hospital studies. Suppose, for example, that $N_{arrests} = 250\,000$, $P_{in\text{-}hosp} = 0.2$, $\Delta P_{rosc} = 0.2$, and $P_{longterm} = 0.3$, then:

$$\Delta N_{survivors} = 3000 \text{ extra survivors}$$

Although IAC-CPR itself is a simple manual technique, the costs of implementing it widely for professional rescuers in hospitals would be significant. Every professional rescuer course, adult and pediatric, available from the American Heart Association and other organizations internationally would require revision of instructor manuals, student manuals, videotapes, and slides. If such revisions were done as part of the normal cycle of guideline revisions, every 5–10 years, then the added cost of including IAC-CPR with other revisions may well be reasonable. Similarly, there would be the cost of retraining CPR instructors. If upgrades in manikins for training were required (see the following Section 7.3) to include abdominal pressure monitors, then these costs would need to be included as well.

If use of IAC-CPR were expanded from in-hospital resuscitations by professional rescuers to out-of-hospital resuscitations by professional rescuers, the logistical limitation of adequate personnel comes into play. Most EMS systems how have only two professional rescuers per vehicle. This limitation would preclude IAC-CPR in those systems, either limiting benefit, or increasing cost dramatically if a third paid rescuer were included on ambulances. This limitation was first noted by Mateer et al. [45], who could not do IAC-CPR during transport of patients in their initial out-of hospital study. For this reasons it would seem prudent to limit initial clinical implementation of IAC-CPR to use by professional rescuers in hospitals.

7.3. Teaching IAC-CPR

A few issues arise regarding teaching IAC-CPR, since any technique, inadequately learned and performed, will not be effective. The following is a synopsis of important points, illustrating that teaching and learning the technique of IAC should not be difficult.

The recommended technique of abdominal compression is adapted from that described by Sack and coworkers [1], who had the most favorable clinical results. Use a two-handed, straight-armed technique similar to that for chest compressions. The abdominal compression point is in the midline, one-half hand width (5 cm) headward of the umbilicus. To ensure proper hand placement on the abdomen, the umbilicus should be visible below the rescuer's hands as a midline landmark. Apply pressure with heel of the hand straight down at the abdominal compression point, keeping fingers off the abdomen.

The amount of force applied should be sufficient to generate approximately normal mean arterial pressure (95 mmHg) within the abdomen near the abdominal aorta. This value is similar to that reported to give good results in animal studies and in theoretical models. It is also less than that required to produce objectionable discomfort in an awake, conscious volunteer [51]. As has been previously described, this is the same amount of force required for palpation of the abdominal aortic pulse during an ordinary physical examination of the abdomen and is, therefore, not excessive [51].

It is quite easy to modify a standard whole body mannequin for the teaching and practice of three-rescuer IAC-CPR. One can add extra foam rubber to the lower thoracic compartment of the manikin and also to the abdominal compartment of the manikin to simulate soft tissues. The next step is to wrap a standard arm blood pressure cuff around a rolled towel and place it in the abdominal compartment beneath the abdominal compression point (5-cm headward of the umbilicus in the midline). Then bring the tubing, aneroid manometer

Table 7
Details of complexity analysis of various basic life support maneuvers done by lay or proffessional rescuers

Action	Basic steps	Variations
Open airway	1. Tilt head	1. Standard head tilt
	2. Lift chin or jaw thrust	2. Injured head or neck
Call 911	1. Call 911	1. Alone
	2. Get AED	2. Have help
Start breathing	1. Check breathing (look, listen, feel)	1. Mouth-to-mouth
	2. Mouth seal	2. Face shields
	3. Two slow breaths	3. Face masks
	4. Watch chest rise	
Start circulation	1. Maintain head tilt	1. Lay or professional
	2. Finds signs of circulation	
	3. Check for signs of circutaion	
	4. Find compression position	
	5. Position hands	
	6. Begin compressions	
Place victim in recovery position	1. Kneel	1. Victim keeps breathing
	2. Arm position waving goodbye	2. Victim stops breathing
	3. Other arm position	
	4. Grasp hand	
	5. Pull and roll	
	6. Adjust hand and knee	
	7. Tilt head	
	8. Check breathing	
	9. Verify 911 call	
Deal with choking	1. Position victim	1. Conscious, standard
	2. Check ability to speak and/or airway	2. Unconscious, standard
	3. Get in position for Heimlich	3. Conscious, obese or pregnant
	4. Do Heimlich	4. Unconscious, obese or pregnant
	5. Check results	
	6. Do finger sweeps	
	7. Repeat as needed	
Use AED	1. Turn on machine	1. Water present
	2. Apply electrodes	2. Pacemaker
	3. Analyze	3. Transdermal patch
	4. Shock sequence	4. Hairy chest
	5. No shock sequence	5. Children
Perform IAC	1. Locate compression site	1. Standard
	2. Compress during chest release	2. Pregnancy or distended abdomen

gauge, and squeeze bulb out at the belt-line so they are visible to the trainees. Tape target pressure markers on the manometer dial at 20 and 120 mmHg. Inflate the cuff to a resting pressure of 20 mmHg. During practice coach trainees to hit the target pressure of 120 during IAC and release to a target pressure of 20 during chest compression. Failure to release abdominal pressure can lead to liver injury during the subsequent chest compression.

One can initiate trainees to the rhythm and mechanics of manual abdominal compressions in the following sequence: Let two experienced rescuers perform two-rescuer CPR on the manikin as usual. The third (abdominal) rescuer, who is the trainee, takes position on opposite side of victim from chest compressor at the level of the abdomen. The chest compressor says, "You press here whenever I release", pointing to the abdominal compression point. The chest compressor counts "one-AND-two-AND-three-AND...". The abdominal rescuer applies pressure during "AND". Abdominal compression is also maintained during mouth-to-mouth or bag-valve-mask rescue breaths to prevent gastric inflation with air [43]. It is helpful to start with slow-motion practice and then gradually to increase toward a normal compression rate. After the rhythm is mastered the trainee can focus on hitting the target pressure on the manometer. These details suggest that IAC-CPR will be easy to teach and easy to learn.

7.4. *Protocols for implementation*

In keeping with current guidelines for ACLS [4] it is best not to use IAC-CPR as a last ditch effort on individuals who have already failed conventional resuscitation efforts. Such a strategy ignores the results of the best clinical research studies on the subject. Outcome can be improved if IAC-CPR is begun as first line therapy in a hospital [1]. However, IAC is known to be relatively ineffective in the failed ACLS model [52]. Another known failure mode is the delayed institution of IAC-CPR after the unknown and varying down times of out-of-hospital cardiac arrest and failed initial resuscitation by standard CPR [37]. The published evidence does not support the use of IAC-CPR as second line therapy. At best the technique simply doubles blood flow during CPR. Three rescuer IAC-CPR is not a revolution, but rather a modest evolution and extension of conventional two-rescuer CPR, which can improve hemodynamics and outcome when performed by trained professionals in a hospital setting.

8. Summary

IAC-CPR is an orphan innovation for a major public health menace in the developed world—sudden cardiac death. Having been independently discovered in Japan, Israel, the United Kingdom and the United States by diverse researchers primarily interested in other topics, it seems to have been poorly championed and poorly advertised in the scientific community. Mentioned as an alternative adjunct in American Heart Association guidelines since 1992, the method is still rarely used. A review of published evidence indicates that IAC-CPR has a sound physiologic basis, does produce improved hemodynamics, and at the very least improves short-term resuscitation success (return of spontaneous circulation) in human beings, when initiated early in the resuscitation protocol.

Analysis of all available randomized clinical trials, including pre-hospital and in-hospital resuscitations, shows IAC-CPR by trained health professionals improves the probability of return of spontaneous circulation compared with standard CPR (Fig. 2(A), $P < 0.01$). When analysis is limited to in-hospital studies only, the improvement in return of spontaneous circulation is highly statistically significant (Fig. 2(B), $P < 0.0001$). Hemodynamic studies in a variety of animal and mechanical models generally show 50–100% improvement in artificial circulation and coronary perfusion pressure with the addition of IAC. Complications of IAC have been negligible in over 400 patients studied. There remains some uncertainty about the practicality and efficacy of out-of-hospital use of IAC, pending further research. Given the issues of increased cost, decreased practicality, and reduced effectiveness in out-of-hospital or pre-hospital settings, it is reasonable at the present time to recommend more widespread clinical use of IAC-CPR by trained professional rescuers in a hospital setting. Since the most favorable clinical results have been obtained when IAC-CPR is applied from the beginning of resuscitation, early application of the technique is to be encouraged. Use of IAC-CPR as a last-ditch effort after prolonged, failed ACLS is not recommended and is only marginally effective.

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