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1 **Cadaver Models for Cardiac Arrest: A Systematic Review and Perspectives**

2

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21

22 **ABSTRACT**

23 **Aim:** To provide an overview of cadaver models for cardiac arrest and to identify the most  
24 appropriate cadaver model to improve cardiopulmonary resuscitation through a systematic  
25 review.

26 **Methods:** The search strategy included PubMed, Embase, Current contents, Pascal,  
27 OpenSIGLE and reference tracking. The search concepts included “heart arrest”,  
28 “cardiopulmonary resuscitation” and “cadavers”. All studies, published until February 2019,  
29 in English or French, on research or simulation in the field of cardiac arrest and using cadaver  
30 models were eligible for inclusion.

31 **Results:** Overall, 29 articles out of the 244 articles located were selected. The characteristics  
32 of the studies and the cadaver models were heterogenous. Indeed, 31% of the studies  
33 lacked a proper description of the model used and its specificities. Fresh cadavers were used  
34 in 55% of the studies and chest compressions were performed in 90%. This model was  
35 appreciated for its realism in terms of mechanical properties and tissue conservation. Thiel-  
36 embalmed cadavers also showed promising results concerning lung and chest compliance.  
37 The lack of circulation stood out as the strongest limitation of all types of human cadaver  
38 models.

39 **Conclusion**

40 Four types of cadaver models are used in cardiac arrest research. The great heterogeneity of  
41 these models coupled with unequal quality in reporting makes comparisons between studies  
42 difficult. There is a need for uniform reporting and standardisation of human cadaver models  
43 in cardiac arrest research.

44 **Keywords:** Heart arrest; Resuscitation; Cadaver; Cardiac arrest; Cardiopulmonary  
45 resuscitation

46 **Abbreviations:** CPR, cardiopulmonary resuscitation; HCM, human cadaver model

47

## 48 **INTRODUCTION**

49 Although progress has been made in cardiac arrest response and management, patients'  
50 outcome has barely improved over the last 30 years [1,2]. The fine pathophysiology of  
51 cardiac arrest remains unclear, especially the interaction between ventilatory and circulatory  
52 support during resuscitation [3].

53 Several limits need to be taken into account to explain the complexity of experimental and  
54 clinical research in this field [4]. First, cardiac arrest mainly occurs out of hospitals and  
55 physiologic parameters change quickly after occurrence, which results in difficulties  
56 exploring the pathophysiology of this event. Second, ethical concerns may be an obstacle to  
57 research with these patients, who obviously are not able to give their consent prior to the  
58 intervention and for whom medical care has to be optimal and efficient. Lastly, the  
59 heterogeneity of patients and their precipitating pathologies are also a constraint.

60 Animal research, mainly on swine models, has provided some translational discoveries but  
61 also has several limitations [5,6]. Even if swine, among other animal models, appears to have  
62 the most similar thorax shape to humans, the slight differences in chest morphology make it  
63 difficult to extrapolate the effect of chest compressions. The differences in global  
64 cardiopulmonary physiology also restricts the comparability of the models [7-9].

65 Manikin trials are widely used for training purposes in the field of cardiac arrest [10–12],  
66 although the transfer of skills learned on simulation tools into clinical practice is still being  
67 discussed [13,14]. Some manikin-based studies also intended to explore cardiopulmonary  
68 resuscitation (CPR) pathophysiology [15]. Even if findings obtained on manikin-based studies  
69 are sometimes directly extrapolated to clinical practice [16], this needs to be done  
70 cautiously. Manikin models are an approximate representation of physiological observations

71 and measurements made on patients [17] and therefore cannot be used to explore  
72 pathophysiology to achieve a better understanding.

73 Since human cadavers are not typically used for resuscitation training or research, the aim of  
74 this review was to reference studies on cardiac arrest or CPR using human cadaver models  
75 (HCMs) and to give a complete overview of their characteristics. Potential limiters of an HCM  
76 are the condition of the body, how it is stored and prepared, time interval since death and  
77 its accessibility. However, HCMs have the potential to provide new information related to  
78 the mechanics of CPR, especially when trying to elucidate the mechanisms of interactions  
79 between anatomic elements. Additionally, this model allows sophisticated physiologic  
80 monitoring that could not be attained in a consistent methodological design in live humans.  
81 Finally, HCMs make it possible to explore various resuscitation techniques on the same  
82 model, in comparison with animal models which often require a new animal for each test.  
83 No systematic review has yet been published on this subject. We therefore aimed to (1)  
84 report a precise analysis of the cadaver models used in the field of cardiac arrest research,  
85 (2) list the research fields explored in those studies, (3) synthesise the advantages and  
86 drawbacks mentioned by the authors of each HCM and finally (4) imagine an ideal HCM  
87 based on previous observations.

88

## 89 **METHODS**

### 90 **Eligibility Criteria**

91 Studies concerning the use of a cadaver model to explore cardiac arrest pathophysiology or  
92 to assess the effectiveness of a new CPR method, as well as studies using HCMs to simulate  
93 cardiac arrest for learning and/or teaching goals, were eligible for this systematic review.

94 Cadaver models used for any fields other than CPR or cardiac arrest and studies on animals

95 were excluded. Cadaver models that could be included in this study were identified through  
96 a systematic literature review (**Fig. 1**). It was conducted in accordance with current  
97 guidelines on systematic literature reviews and it complied with the Preferred Reporting  
98 Items for Systematic reviews and Meta-Analyses (PRISMA) statement [18].

99

## 100 **Search Strategies and Data Extraction**

101 Studies were identified through electronic databases. The following key words were used:  
102 “heart arrest”, “cardiac arrest”, “cardiopulmonary resuscitation”, “cadaver”. Only articles  
103 with the full text available in English or French were selected. No type of document  
104 restriction was applied and no methodology filters were used. All studies published until  
105 February 2019 were eligible for inclusion. This search was applied to Medline and adapted to  
106 Embase, Current Contents and Pascal electronic databases. We also searched the grey  
107 literature (Open SIGLE). The precise research approach for identifying potential eligible  
108 studies is described in **Appendix A**. One author (HD) conducted the literature search with  
109 the help of a professional librarian (VD) to produce a database of references. Finally, a  
110 secondary search was conducted by scanning the reference lists of the original articles  
111 retrieved.

112 Two review authors (HD, GD) independently and blindly screened the titles and abstracts of  
113 all the records identified by the search strategy, in accordance with the Cochrane  
114 recommendations [19]. For this initial screening, all search results were imported into  
115 reference management software and duplicates were removed. The screening process  
116 assessed whether the citation: (1) reported data from an original research study using HCMs  
117 and (2) focused on cardiac arrest or cardiopulmonary resuscitation. If both criteria were met,  
118 the study was considered eligible. The two review authors rated each citation using a

119 “relevant”, “irrelevant” or “unsure” designation. Only full-text articles that received a  
120 “relevant” or “unsure” classification from at least one of the two review authors were  
121 retrieved for citations. Out of 244 records identified, discrepancies of eligibility assessment  
122 between authors were encountered for 14 references. Full-text articles of records identified  
123 as being potentially relevant were independently assessed by the two authors for inclusion.  
124 Disagreements on eligibility were resolved in discussion between the reviewers. The reasons  
125 for excluding studies were recorded. A PRISMA-style flow diagram was drawn to illustrate  
126 the process of primary study selection from identification to inclusion in the systematic  
127 review (**Fig. 1**).

128 The following data were collected for each study eligible when available: the type of cadaver  
129 and its characteristics and the intended purpose of the study. We also reported if chest  
130 compressions were applied and their modalities, if ventilation was performed, if declotting  
131 or perfusion techniques were used and if any other kind of equipment was used on the  
132 cadaver. Finally, we looked for any mention of the model’s quality assessment or limitations  
133 reported in those studies.

134

### 135 **Risk of Bias (Quality) Assessment**

136 To provide an overview of the quality level of the studies included, we used the Cochrane  
137 RoB Tool developed by the Cochrane Collaboration [20] to report the risk of bias (**Appendix**  
138 **B**). This tool evaluates seven different quality domains: (1) random sequence generation, (2)  
139 allocation concealment, (3) blinding of participants and personnel, (4) blinding of outcome  
140 assessment, (5) incomplete outcome data, (6) selective reporting and (7) other biases. The  
141 Cochrane RoB Tool was developed for randomised clinical trials and is not completely  
142 adequate for studies on cadaver models which include experimental studies. This means

143 that some aspects of the quality assessment process needed to be adapted to the  
144 characteristics of the studies using HCMs. When the risk of bias for a specific domain was  
145 considered irrelevant in a given study by the authors, it was graded as “low”. We graded as  
146 “unclear risk of other biases” studies lacking a description of the model’s characteristics,  
147 preparation or storage conditions in a way resulting in non-reproducible study conditions.

148

### 149 **Statistical Analysis**

150 The results were reported as numbers and percentages for categorical variables and means  
151 and standard deviations or minimum and maximum values for continuous variables.

152

153

## 154 **RESULTS**

### 155 **Literature Search**

156 A total of 283 citations were identified in the database search (**Fig. 1**). The secondary search  
157 yielded 12 additional records, identified from citation and reference tracking. After removing  
158 duplicates, a total of 244 studies were screened on the basis of the title and abstract. The  
159 full text of 40 articles was retrieved for a more thorough eligibility review. Eleven citations  
160 did not fulfil the inclusion criteria and were excluded. Finally, 29 articles were included. Four  
161 different cadaver preparation models were used.

162

### 163 **Characteristics of the Studies Included**

164 Sixteen (55%) studies used fresh cadavers, six (21%) used “newly deceased” cadavers, four  
165 (14%) used Thiel-embalmed cadavers and three (10%) used fresh-frozen cadavers. No study  
166 used formalin-embalmed cadavers. A brief technical description of each model is

167 summarised in **Table 1**. The number of cadavers used in each study was  $12\pm 11$ . Within  
168 studies, interventions were performed several times on the same cadaver with an average  
169 number of uses of  $6\pm 11$  times. The age of cadavers was indicated in 15 (52%) studies, with a  
170 mean of 71 years (range, 58–84). Only five studies specified the cadaver storage  
171 temperature, four of them used fresh cadavers, not frozen, and cadavers were kept at 4°C in  
172 three of these, one study kept them at 22°C for a very short time. One study using Thiel-  
173 embalmed cadavers mentioned a storage temperature of 20°C. Ten (34%) studies used  
174 automated chest compressions, seven (24%) used manual chest compressions, three (10%)  
175 used open chest cardiac massage and four (14%) used a combination of the above. Thirteen  
176 (45%) studies used ventilation on cadavers, either manual or mechanical (**Table 3**).

177 The studies explored seven main domains: ventilation and airway management, 14 (48%);  
178 haemodynamics, five (17%); thoraco(s)tomy, two (7%); mechanical properties of the chest,  
179 four (14%); defibrillation safety, two (7%); bispectral index monitoring, one (3%); and  
180 intraosseous access, one (3%) (**Table 2**). All relevant studies were interventional in design.

181

## 182 **Risk of Bias Within Studies**

183 The risk of bias assessment is summarised in **Appendix B**. The main issue was that  
184 considering the main outcome measured, 22 (76%) studies were not able to blind  
185 participants to the intervention type. In addition, there was either unclear or no blinding of  
186 assessors in 25 (86%) studies. The model description was considered adequate if at least five  
187 out of eight of the following criteria were specified in the study: type of cadaver, storage  
188 temperature, number of cadavers used, number of uses per cadaver, age, weight, gender  
189 and post-mortem time interval. Nine (31%) studies were considered as non-reproducible  
190 due to insufficient model description. There was insufficient information on the sequence

191 generation process and/or allocation concealment in five studies (17%). One study [21]  
192 seemed to incompletely report its outcomes. Finally, there was substantial (25%)  
193 unexplained drop-out in one study [22] and 27% of the data were missing in one of the  
194 interventions in a crossover study [23].

195

## 196 **Fresh Cadavers**

197 Fresh cadavers entail a human body never frozen or embalmed post-mortem, generally kept  
198 for up to 72 h in a refrigerated area and then used for research or teaching. No preparation  
199 or declotting is performed. In this systematic review, 16 (55%) studies used fresh cadavers,  
200 and these records studied six main research areas: airway management, seven studies (44%)  
201 [24–30]; mechanical properties of the chest, three studies (19%) [17,31,32];  
202 haemodynamics, two studies (12.5%) [33,34]; defibrillation safety, two studies (12.5%)  
203 [22,35], intraosseous access, one study (6%) [36]; and one study explored bispectral index  
204 monitoring and used a fresh cadaver for artefact control (6%) [37]. The main advantages  
205 reported of using fresh cadavers were: its accurate morphology and tissue conservation  
206 making it possible, for example, to reflect the conditions of endotracheal intubation,  
207 accurately estimate regurgitation risks in humans having CPR, obtain a stable transthoracic  
208 impedance over time and characterise thoracic viscoelastic properties. The authors also  
209 reported good results in haemodynamic simulations since they were able to measure a  
210 pressure rise during chest compressions; one study assessed achievement of venous  
211 circulation from a peripheral vessel to pulmonary vessels with automated chest  
212 compressions [34], and another one reported haemodynamic findings similar to pigs during  
213 ventricular fibrillation [33]. On the other hand, the limitations of this model were that no  
214 right-to-left circulation was achieved, nor left-to-right capillary flow, resulting in blood flow

215 measurement being impossible. Moreover, the authors reported that the loss of vascular  
216 tone, the modified biomechanics of the tissues and the modification of lung compliance due  
217 to beginning rigor mortis were also limitations to the realism of the model. Finally, one  
218 group regretted that human cadavers consisted of elderly patients with a low body mass  
219 index, which could reduce the comparability with cardiac arrest patients, and one study  
220 decided to use fresh-frozen cadavers because they considered fresh cadavers too expensive  
221 [38].

222

### 223 **Fresh-Frozen Cadavers**

224 Fresh-frozen cadavers consist of human bodies frozen a few hours after death (only one  
225 study mentioned the post-mortem interval between death and freezing:  $36 \text{ h} \pm 12$ ) and then  
226 thawed before use. Like fresh cadavers, no preparation or declotting techniques are used. In  
227 this systematic review, three studies used fresh-frozen cadavers (10%), one explored the  
228 mechanical properties of the chest (33%) [38], one assessed an open chest cardiac massage  
229 device (33%) [39] and one studied ventilation (33%) [40]. None of them specified the  
230 freezing temperature. One study exploring capnographic waveforms during ventilation  
231 pointed out the advantage of the similarity of cadaver models with the low- or no-perfusion  
232 state observed in cardiac arrest patients [40]. The authors reported a lack of realism of the  
233 lung and chest compliance and the frailty of the cadavers compared to patients or fresh  
234 cadavers. Once again, the lack of circulation was found to be a strong limitation of the model  
235 since complications such as bleeding could not be simulated, as well as the lack of a real gas  
236 exchange despite ventilation. One study mentioned high cost as a limitation to the number  
237 of specimens used and therefore to the power of the study [38].

238

239 **Thiel-Embalmed Cadavers**

240 Thiel-embalmed cadavers are soft-embalmed cadavers using a method described by Walter  
241 Thiel in 1992 [41] and updated in 2002 [42]. It consists in the application of an intravascular  
242 injection formula containing glycol, various salts, boric acid, chlorocresol, alcohol and low  
243 levels of formaldehyde, and maintaining the corpses submerged for a determinate period of  
244 time in the immersion solution in a tank. After immersion, it is possible to maintain the  
245 corpses in a hermetically sealed container, thus avoiding dehydration outside the tank.  
246 Cadavers embalmed with Thiel methods can be used repeatedly and be preserved for up to  
247 3 years, in contrast with fresh and fresh-frozen cadavers. In this review, four studies used  
248 Thiel-embalmed cadavers (14%), three of them were conducted by the same research team  
249 and studied ventilation (75%) [43–45] and one studied thoracotomy training (25%) [46]. All  
250 the studies included using Thiel-embalmed cadavers were published after 2015, even though  
251 this embalming method has been known since 1992. The main advantages reported  
252 concerning the use of Thiel-embalmed cadavers were the lifelike aspect of the anatomy and  
253 mechanical properties, in particular the preserved elasticity and flexibility of the tissues as  
254 well as lung and chest wall compliance and resistance that were found to be comparable to  
255 values reported in critically ill patients. In addition, this model also had the advantage of  
256 being stable over time in terms of resistance and compliance and reproduces the airway  
257 opening and collapse phenomenon observed in cardiac arrest patients. Once again, the lack  
258 of blood flow and perfusion was reported by the authors as a shortcoming. Charbonney et  
259 al. [44] also mentioned that Thiel-embalmed cadavers seemed to be particularly prone to  
260 pulmonary derecruitment. The other disadvantage reported was the fact that Thiel-  
261 embalmed method requires expertise available in only certain laboratories.

262

263 **Newly Deceased Cadavers**

264 Six records used newly deceased cadavers (21%) to study ventilation and airway  
265 management [47–49] and haemodynamics [21,23,50]. These studies were carried out in the  
266 minutes following death in ICU and emergency departments, or on organ donors. No  
267 description of the models was provided, but the authors report that the cadaver population  
268 used could differ from cardiac arrest patients given that most of the subjects died of  
269 multiorgan failure or had severe pulmonary complications before death. One study noted  
270 that the model was found to be unstable over time [50]. As for ethical concerns, four studies  
271 reported or implied that informed consent was not required by ethics committees, one  
272 study mentioned that permission was obtained with the permit for organ retrieval [50] and  
273 consent of the family was obtained in one study [23]. Interestingly enough, all studies using  
274 newly deceased cadavers except one [23] were published before the beginning of the 21st  
275 century.

276

277 **DISCUSSION**

278 To our knowledge, this review is the first to describe the different human cadaver models  
279 that have been used to date in cardiac arrest research. We found that four different models  
280 were used – newly deceased, fresh cadavers, fresh-frozen cadavers and Thiel-embalmed  
281 cadavers with the specific advantage and limitations for each model. The majority of the  
282 studies were conducted on fresh cadavers.

283 Understanding the physiology of cardiopulmonary resuscitation during cardiac arrest has  
284 been a challenge for many years. Pre-clinical research in this field is often long and  
285 fastidious. Although animal studies have tried to reflect the clinical scenario, these models  
286 fail to properly simulate human cardiopulmonary pathophysiology. Likewise, manikin

287 simulation cannot be extrapolated with certainty to patients in cardiac arrest because it is  
288 only a representation of physiological observations and measurements taken on patients. It  
289 has been shown that the results obtained on manikins may fail to translate to actual out-of-  
290 hospital cardiac arrest patients [51–53]. This might be a root cause for the negative results of  
291 many clinical studies with promising experimental findings [54–57]. High-quality post-  
292 resuscitation care is the key component to improve survival with good neurological outcome  
293 [58,59]. Human cadaver models provide new perspectives in resuscitation research through  
294 their ability to enable sophisticated physiologic monitoring that could not be attained in a  
295 clinical setting. In addition, their human morphology allows researchers to overcome  
296 anatomical differences which might burden animal studies.

297 The studies included in this review explored two main areas, ventilation and airway  
298 management, and haemodynamics. Most studies using Thiel-embalmed cadavers explored  
299 ventilation and showed promising results, particularly concerning the similarity of  
300 respiratory system behavior with cardiac arrest patients. Haemodynamics was studied using  
301 either fresh cadavers or newly deceased cadavers. Three studies measured blood pressure in  
302 cadaver models, two of them using newly deceased cadavers were evaluated with a high risk  
303 of bias [23,50]. One study with good methodology [33] measured arterial blood pressure in a  
304 fresh cadaver model and reported encouraging findings of similar blood pressure curves to  
305 those obtained on pigs in ventricular fibrillation. Nevertheless, the lack of circulation was  
306 almost systematically reported as a limit to HCM and research in this area should be  
307 pursued.

308 Taking into account the weaknesses and strong points underlined by the authors, we have  
309 described an “ideal” cadaver model of cardiac arrest. What seemed important for the  
310 realism and accuracy of the model was its lifelike anatomy and tissue conservation as well as

311 similarity with cardiac arrest patients in terms of chest and lung compliance and resistance.  
312 Stability over time appeared as another important point to be emphasised given that human  
313 cadaver research can be expensive. The lack of circulation was definitely the most common  
314 and important limitation of the models described; therefore we suggest that this ideal model  
315 should enable left-to-right circulation. To reproduce circulation, the use of a fresh cadaver  
316 seemed to be a reasonable option as haemodynamic studies have already reported  
317 satisfactory results [33,34]. The drawback of this model, as previously reported, is the lack of  
318 embalming, which requires the cadaver to be disposed of after the procedure. Moreover,  
319 although it has not been reported in the studies included, prolonged cardiac massage on a  
320 perfused cadaver inevitably leads to pulmonary and limb oedema due to the altered vascular  
321 permeability of fresh cadavers. An interesting lead to explore could be to try and reproduce  
322 circulation on a Thiel-embalmed cadaver since this model shows greater similarities in terms  
323 of lung and chest compliance and resistance, with critically ill patients, and is more stable  
324 over time compared to fresh cadavers. This has never been done to explore cardiac arrest  
325 pathophysiology, but one team has successfully perfused the aorta of a Thiel-embalmed  
326 cadaver to simulate aortic endovascular procedures [60].

327 Even if human cadavers are not yet traditionally used for resuscitation training or research, it  
328 is interesting to note that 60% of the studies included in this review were published in the  
329 past 4 years, which confirms a definite trend towards this approach in cardiac arrest  
330 research (**Fig. 2**).

331 Furthermore, “time for procedure” was found to be the main outcome measured in a fair  
332 number of the studies included [24–26,36,39,46], underscoring the fact that cadaver models  
333 are used in feasibility studies to test new medical devices. In extension, this also opens the  
334 door to the idea that an HCM could be used for training and education in cardiac arrest

335 management. Indeed, their lifelike features could enable realistic training and simulation of  
336 invasive procedures and/or new CPR strategies in a controlled and risk-free environment.

337

338 A strong limitation reported by the authors was that cadaver research could be expensive  
339 and therefore limits the size of the samples used. We attempted to evaluate the cost of each  
340 cadaver model but the literature in this field is poorly documented. We must admit that  
341 maintenance of a cadaver lab, storage, technical support, operative equipment and  
342 embalming fluids has cost implications that might be too complex to calculate a cost per  
343 cadaver. We identified three studies mentioning “preparation” costs of cadaver models, all  
344 of them concerning surgical training. Benkhadra et al. [61] estimated the price of a Thiel-  
345 embalmed cadaver at about 300 € while Hammer et al. [62] proposed a modified Thiel  
346 embalming method which could almost cut the price in half. This modified Thiel method was  
347 estimated around 437 €, which is inconsistent with Benkhadra et al.’s findings. Both studies  
348 estimated the price of formaldehyde-based cadavers near 30 €. Finally, Mitchell et al. [63]  
349 priced a fresh cadaver model between 900 € and 1800 € depending on the presence or  
350 absence of the extremities and head, as opposed to a porcine model’s cost, which was  
351 estimated at 350 € per animal. Comparatively, another study using swine models in burn  
352 research estimated the price at 517 € per animal. Once again, this estimation does not  
353 include technical support, storage or operative equipment [64]. Cadaver-related costs,  
354 however, can be mitigated using the same cadaver for other purposes and by other  
355 disciplines. In this way, the Thiel-embalmed cadaver could be the most sustainable model  
356 used in these studies because it was found to be reusable after investigation and stable over  
357 time.

358

359 Finally, an “ideal” cadaver model is probably an unrealistic goal, as no single HCM can  
360 encompass the complexity of a cardiac arrest patient. Various models are essential to  
361 answer specific research questions. Based on the findings of this systematic review, we  
362 consider fresh cadaver models as the most appropriate model to investigate hemodynamic  
363 during CPR, even if Thiel-embalmed cadavers have never been tested for this purpose.  
364 However, Thiel-embalmed cadavers could represent strong models to study ventilation in  
365 cardiac arrest, and it should probably be researchers’ first choice for such studies.  
366 Investigators should adapt their choice of HCM in accordance with the scientific question at  
367 hand, but their methodology must be reported and well documented to enable  
368 reproducibility. The lack of uniform reporting limits our ability to compare the results  
369 obtained in these studies. Such discrepancy might be further enhanced by the large period  
370 of literacy search. Studies that were performed almost 60 years ago substantially differ from  
371 the more recent ones, due at least partly to the fact that the methodology of research in this  
372 field has greatly improved. Accordingly, comparison might be challenging. Nevertheless,  
373 there is a need to standardise cardiac arrest research and reporting on human cadaver  
374 models. Ideally, the Utstein-Style Guidelines for Uniform Reporting of Laboratory CPR  
375 Research [8] could be adapted to research on cadaver models. These guidelines were  
376 published in 1996 with the aim of standardising the reporting of animal cardiac arrest  
377 research. Similar guidelines for studies on cadavers might improve comparability and  
378 reproducibility of such studies.

379

## 380 **CONCLUSION**

381 Four types of cadaver models were reported, newly deceased, fresh cadavers, fresh-frozen  
382 cadavers and Thiel-embalmed cadavers. The majority of the studies used fresh cadavers.

383 Ventilation and airway management was the most common topic explored. The lack of  
384 circulation was found to be the main drawback of human cadavers regardless of the type of  
385 model. The studies included lacked uniform reporting, which limited our ability to compare  
386 the results obtained.

387

#### 388 **Conflict of Interest**

389 The authors declare that they have no conflict of interest in connection with the article.

390

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393

394

- 396 1] Sandroni C, Nolan J, Cavallaro F, Antonelli M. In-hospital cardiac arrest: incidence,  
397 prognosis and possible measures to improve survival. *Intensive Care Med* 2007;33:237–  
398 45.
- 399 [2] Chen LM, Nallamothu BK, Spertus JA, Li Y, Chan PS, American Heart Association’s Get  
400 With the Guidelines-Resuscitation (formerly the National Registry of Cardiopulmonary  
401 Resuscitation) Investigators. Association between a hospital’s rate of cardiac arrest  
402 incidence and cardiac arrest survival. *JAMA Intern Med* 2013;173:1186–95.
- 403 [3] Ashoor HM, Lillie E, Zarin W, et al. Effectiveness of different compression-to-ventilation  
404 methods for cardiopulmonary resuscitation: A systematic review. *Resuscitation*  
405 2017;118:112–25.
- 406 [4] Nichol G, Leroux B, Wang H, et al. Trial of Continuous or Interrupted Chest  
407 Compressions during CPR. *N Engl J Med* 2015;373:2203–14.
- 408 [5] Vognsen M, Fabian-Jessing BK, Secher N, et al. Contemporary animal models of cardiac  
409 arrest: A systematic review. *Resuscitation* 2017;113:115–23.
- 410 [6] Fabian-Jessing BK, Vallentin MF, Secher N, et al. Animal models of cardiac arrest: A  
411 systematic review of bias and reporting. *Resuscitation* 2018;125:16–21.
- 412 [7] Prat N, Rongieras F, de Freminville H, et al. Comparison of thoracic wall behavior in  
413 large animals and human cadavers submitted to an identical ballistic blunt thoracic  
414 trauma. *Forensic Sci Int* 2012;222:179–85.
- 415 [8] Idris AH, Becker LB, Ornato JP, et al. Utstein-style guidelines for uniform reporting of  
416 laboratory CPR research. A statement for healthcare professionals from a Task Force of  
417 the American Heart Association, the American College of Emergency Physicians, the  
418 American College of Cardiology, the European Resuscitation Council, the Heart and  
419 Stroke Foundation of Canada, the Institute of Critical Care Medicine, the Safar Center  
420 for Resuscitation Research, and the Society for Academic Emergency Medicine.  
421 *Resuscitation* 1996;33:69–84.
- 422 [9] Swindle MM, Smith AC, Hepburn BJ. Swine as models in experimental surgery. *J Investig*  
423 *Surg Off J Acad Surg Res* 1988;1:65–79.
- 424 [10] Heitz C, Eyck RT, Smith M, Fitch M. Simulation in medical student education: survey of  
425 clerkship directors in emergency medicine. *West J Emerg Med* 2011;12:455–60.
- 426 [11] Okuda Y, Bond W, Bonfante G, et al. National growth in simulation training within  
427 emergency medicine residency programs, 2003-2008. *Acad Emerg Med Off J Soc Acad*  
428 *Emerg Med* 2008;15:1113–6.
- 429 [12] McLaughlin S, Fitch MT, Goyal DG, et al. Simulation in graduate medical education  
430 2008: a review for emergency medicine. *Acad Emerg Med Off J Soc Acad Emerg Med*  
431 2008;15:1117–29.
- 432 [13] Cook DA, Hatala R, Brydges R, et al. Technology-Enhanced Simulation for Health  
433 Professions Education: A Systematic Review and Meta-analysis. *JAMA* 2011;306:978–  
434 88.
- 435 [14] Ilgen JS, Sherbino J, Cook DA. Technology-enhanced Simulation in Emergency Medicine:  
436 A Systematic Review and Meta-Analysis. *Acad Emerg Med* 2013;20:117–27.
- 437 [15] Wenzel V, Idris AH, Banner MJ, Kubilis PS, Williams JL. Influence of tidal volume on the  
438 distribution of gas between the lungs and stomach in the nonintubated patient  
439 receiving positive-pressure ventilation. *Crit Care Med* 1998;26:364–8.

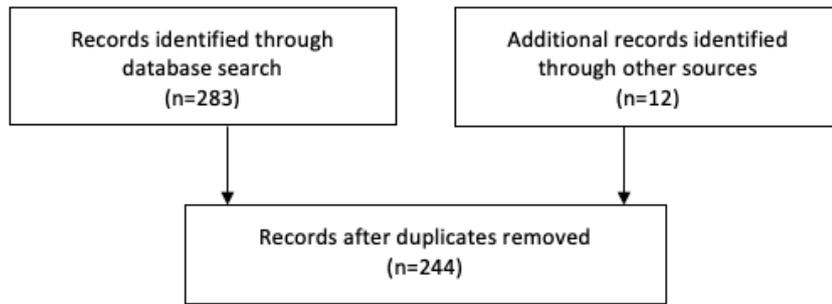
- 440 [16] Koster RW, Baubin MA, Bossaert LL, et al. European Resuscitation Council Guidelines  
441 for Resuscitation 2010 Section 2. Adult basic life support and use of automated external  
442 defibrillators. *Resuscitation* 2010;81:1277–92.
- 443 [17] Eichhorn S, Spindler J, Polski M, et al. Development and validation of an improved  
444 mechanical thorax for simulating cardiopulmonary resuscitation with adjustable chest  
445 stiffness and simulated blood flow. *Med Eng Phys* 2017;43:64–70.
- 446 [18] Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA Statement for Reporting Systematic  
447 Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions:  
448 Explanation and Elaboration. *PLOS Med* 2009;6:e1000100.
- 449 [19] Higgins J, Green S (2011) *Cochrane Handbook for Systematic Reviews of Interventions*.  
450 *Cochrane Collab Part 2*:27-264.
- 451 [20] Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration’s tool for  
452 assessing risk of bias in randomised trials. *BMJ* 2011;343:d5928.
- 453 [21] Skinner DB, Leonard LG, Cooke SA. Resuscitation following prolonged cardiac arrest.  
454 *Ann Thorac Surg* 1971;11:201–9.
- 455 [22] Lemkin DL, Witting MD, Allison MG, Farzad A, Bond MC, Lemkin MA. Electrical exposure  
456 risk associated with hands-on defibrillation. *Resuscitation* 2014;85:1330–6.
- 457 [23] Wei J, Tung D, Sue S-H, Wu S-V, Chuang Y-C, Chang C-Y. Cardiopulmonary Resuscitation  
458 in Prone Position: A Simplified Method for Outpatients. *J Chin Med Assoc* 2006;69:5.
- 459 [24] Truszewski Z, Krajewski P, Fudalej M, et al. A comparison of a traditional endotracheal  
460 tube versus EView SL in endotracheal intubation during different emergency  
461 conditions. *Medicine (Baltimore)* 2016;95.
- 462 [25] Truszewski Z, Czyzewski L, Smereka J, et al. Ability of paramedics to perform  
463 endotracheal intubation during continuous chest compressions: a randomized cadaver  
464 study comparing Pentax AWS and Macintosh laryngoscopes. *Am J Emerg Med*  
465 2016;34:1835–9.
- 466 [26] Cho J, Chung HS, Chung SP, Kim Y-M, Cho YS. Airway scope vs Macintosh laryngoscope  
467 during chest compressions on a fresh cadaver model. *Am J Emerg Med* 2010;28:741–4.
- 468 [27] Segal N, Voiglio EJ, Rerbal D, et al. Effect of continuous oxygen insufflation on induced-  
469 gastric air volume during cardiopulmonary resuscitation in a cadaveric model.  
470 *Resuscitation* 2015;86:62–6.
- 471 [28] Coats TJ, Morgan B, Robinson C, Biggs M, Adnan A, Ruddy G. End-tidal CO<sub>2</sub> detection  
472 during cadaveric ventilation. *Emerg Med J EMJ* 2015;32:753–4.
- 473 [29] Piegeler T, Roessler B, Goliash G, et al. Evaluation of six different airway devices  
474 regarding regurgitation and pulmonary aspiration during cardio-pulmonary  
475 resuscitation (CPR) – A human cadaver pilot study. *Resuscitation* 2016;102:70–4.
- 476 [30] Ruetzler K, Leung S, Chmiela M, et al. Regurgitation and pulmonary aspiration during  
477 cardio-pulmonary resuscitation (CPR) with a laryngeal tube : A pilot crossover human  
478 cadaver study. *PLoS One* 2019;14:e0212704.
- 479 [31] Segal N, Robinson AE, Berger PS, et al. Chest compliance is altered by static  
480 compression and decompression as revealed by changes in anteroposterior chest  
481 height during CPR using the ResQPUMP in a human cadaver model. *Resuscitation*  
482 2017;116:56–9.
- 483 [32] Baubin M, Rabl W, Pfeiffer KP, Benzer A, Gilly H. Chest injuries after active  
484 compression-decompression cardiopulmonary resuscitation (ACD-CPR) in cadavers.  
485 *Resuscitation* 1999;43:9–15.

- 486 [33] Moore JC, Holley J, Segal N, et al. Consistent head up cardiopulmonary resuscitation  
487 haemodynamics are observed across porcine and human cadaver translational models.  
488 Resuscitation 2018;132:133–9.
- 489 [34] Ruddy GN, Robinson C, Amoroso J, Coats T, Morgan B. Could post-mortem computed  
490 tomography angiography inform cardiopulmonary resuscitation research?  
491 Resuscitation 2017;121:34–40.
- 492 [35] Wampler D, Kharod C, Bolleter S, Burkett A, Gabehart C, Manifold C. A randomized  
493 control hands-on defibrillation study—Barrier use evaluation. Resuscitation  
494 2016;103:37–40.
- 495 [36] Szarpak L, Truszewski Z, Smereka J, et al. A Randomized Cadaver Study Comparing First-  
496 Attempt Success Between Tibial and Humeral Intraosseous Insertions Using NIO Device  
497 by Paramedics: A Preliminary Investigation. Medicine (Baltimore) 2016;95:e3724.
- 498 [37] Fatovich DM, Jacobs IG, Celenza A, Paech MJ. An observational study of bispectral index  
499 monitoring for out of hospital cardiac arrest. Resuscitation 2006;69:207–12.
- 500 [38] McKay DR, Fawzy HF, McKay KM, Nitsch R, Mahoney JL. Are chest compressions safe  
501 for the patient reconstructed with sternal plates? Evaluating the safety of  
502 cardiopulmonary resuscitation using a human cadaveric model. J Cardiothorac Surg  
503 2010;5:64.
- 504 [39] Hanouz J-L, Thuaudet S, Ramakers M, et al. Insertion of the minimally invasive direct  
505 cardiac massage device (MIDCM): training on human cadavers. Resuscitation  
506 2002;52:49–53.
- 507 [40] Silvestri S, Ladde JG, Brown JF, et al. Endotracheal tube placement confirmation: 100%  
508 sensitivity and specificity with sustained four-phase capnographic waveforms in a  
509 cadaveric experimental model. Resuscitation 2017;115:192–8.
- 510 [41] Thiel W. The preservation of the whole corpse with natural color. Ann Anat Anat Anz  
511 Off Organ Anat Ges 1992;174:185–95.
- 512 [42] Thiel W. Supplement to the conservation of an entire cadaver according to W. Thiel.  
513 Ann Anat Anat Anz Off Organ Anat Ges 2002;184:267–9.
- 514 [43] Grieco DL, Brochard L, Drouet A, et al. Intrathoracic Airway Closure Impacts CO<sub>2</sub> Signal  
515 and Delivered Ventilation During Cardiopulmonary Resuscitation. Am J Respir Crit Care  
516 Med 2019;199:728–737.
- 517 [44] Charbonney E, Delisle S, Savary D, et al. A new physiological model for studying the  
518 effect of chest compression and ventilation during cardiopulmonary resuscitation: The  
519 Thiel cadaver. Resuscitation 2018;125:135–42.
- 520 [45] Savary D, Charbonney E, Delisle S, et al. Capnographic waveforms obtained in  
521 experimental Thiel cadaver model after intubation. Resuscitation 2017;116:e1–2.
- 522 [46] Puchwein P, Sommerauer F, Clement HG, et al. Clamshell thoracotomy and open heart  
523 massage—A potential life-saving procedure can be taught to emergency physicians.  
524 Injury 2015;46:1738–42.
- 525 [47] Davis K, Johannigman JA, Johnson RC, Branson RD. Lung Compliance Following Cardiac  
526 Arrest. Acad Emerg Med 1995;2:874–8.
- 527 [48] Langhelle A, Sunde K, Wik L, Steen PA. Airway pressure with chest compressions versus  
528 Heimlich manoeuvre in recently dead adults with complete airway obstruction.  
529 Resuscitation 2000;44:105–8.
- 530 [49] Lufkin KC, Ruiz E. Mouth-to-mouth ventilation of cardiac arrested humans using a  
531 barrier mask. Prehospital Disaster Med 1993;8:333–5.

- 532 [50] Rieder CF, Crawford BG, Iliopoulos JI, Thomas JH, Pierce GE, Hermreck AS. A study of  
533 the techniques of cardiac massage with the abdomen open. *Surgery* 1985;98:824–30.
- 534 [51] De Luca A, Sall FS, Saille R, Capellier G, Khoury A. Reliability of manikin-based studies:  
535 an evaluation of manikin characteristics and their impact on measurements of  
536 ventilatory variables. *Anaesthesia* 2015;70:915–21.
- 537 [52] Tomte O, Sunde K, Lorem T, et al. Advanced life support performance with manual and  
538 mechanical chest compressions in a randomized, multicentre manikin study.  
539 *Resuscitation* 2009;80:1152–7.
- 540 [53] Hallstrom A, Rea TD, Sayre MR, et al. Manual Chest Compression vs Use of an  
541 Automated Chest Compression Device During Resuscitation Following Out-of-Hospital  
542 Cardiac Arrest: A Randomized Trial. *JAMA* 2006;295:2620–8.
- 543 [54] Cariou A, Deye N, Vivien B, et al. Early High-Dose Erythropoietin Therapy After Out-of-  
544 Hospital Cardiac Arrest: A Multicenter, Randomized Controlled Trial. *J Am Coll Cardiol*  
545 2016;68:40–9.
- 546 [55] Kim F, Nichol G, Maynard C, et al. Effect of prehospital induction of mild hypothermia  
547 on survival and neurological status among adults with cardiac arrest: a randomized  
548 clinical trial. *JAMA* 2014;311:45–52.
- 549 [56] Argaud L, Cour M, Dubien P-Y, et al. Effect of Cyclosporine in Nonshockable Out-of-  
550 Hospital Cardiac Arrest: The CYRUS Randomized Clinical Trial. *JAMA Cardiol*  
551 2016;1:557–65.
- 552 [57] Debaty G, Maignan M, Savary D, et al. Impact of intra-arrest therapeutic hypothermia  
553 in outcomes of prehospital cardiac arrest: a randomized controlled trial. *Intensive Care*  
554 *Med* 2014;40:1832–42.
- 555 [58] Nolan JP, Soar J, Cariou A, et al. European Resuscitation Council and European Society  
556 of Intensive Care Medicine Guidelines for Post-resuscitation Care 2015: Section 5 of the  
557 European Resuscitation Council Guidelines for Resuscitation 2015. *Resuscitation*  
558 2015;95:202–22.
- 559 [59] Sunde K, Kramer-Johansen J, Pytte M, Steen PA. Predicting survival with good  
560 neurologic recovery at hospital admission after successful resuscitation of out-of-  
561 hospital cardiac arrest: the OHCA score. *Eur Heart J* 2007;28:773–5.
- 562 [60] McLeod H, Cox BF, Robertson J, et al. Human Thiel-Embalmed Cadaveric Aortic Model  
563 with Perfusion for Endovascular Intervention Training and Medical Device Evaluation.  
564 *Cardiovasc Intervent Radiol* 2017;40:1454–60.
- 565 [61] Benkhadra M, Gérard J, Genelot D, et al. Is Thiel’s embalming method widely known? A  
566 world survey about its use. *Surg Radiol Anat SRA* 2011;33:359–63.
- 567 [62] Hammer N, Löffler S, Bechmann I, Steinke H, Hädrich C, Feja C. Comparison of modified  
568 thiel embalming and ethanol-glycerin fixation in an anatomy environment: Potentials  
569 and limitations of two complementary techniques. *Anat Sci Educ* 2015;8:74–85.
- 570 [63] Mitchell EL, Sevdalis N, Arora S, et al. A fresh cadaver laboratory to conceptualize  
571 troublesome anatomic relationships in vascular surgery. *J Vasc Surg* 2012;55:1187–94.
- 572 [64] Abdullahi A, Amini-Nik S, Jeschke M. Animal Models in Burn Research. *Cell Mol Life Sci*  
573 *CMLS* 2014;71:3241–55.
- 574
- 575



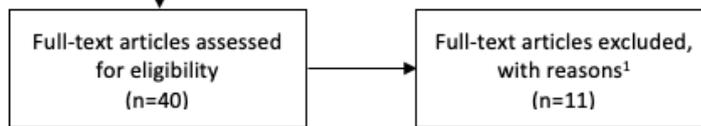
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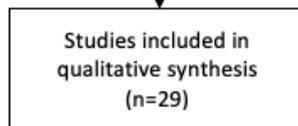
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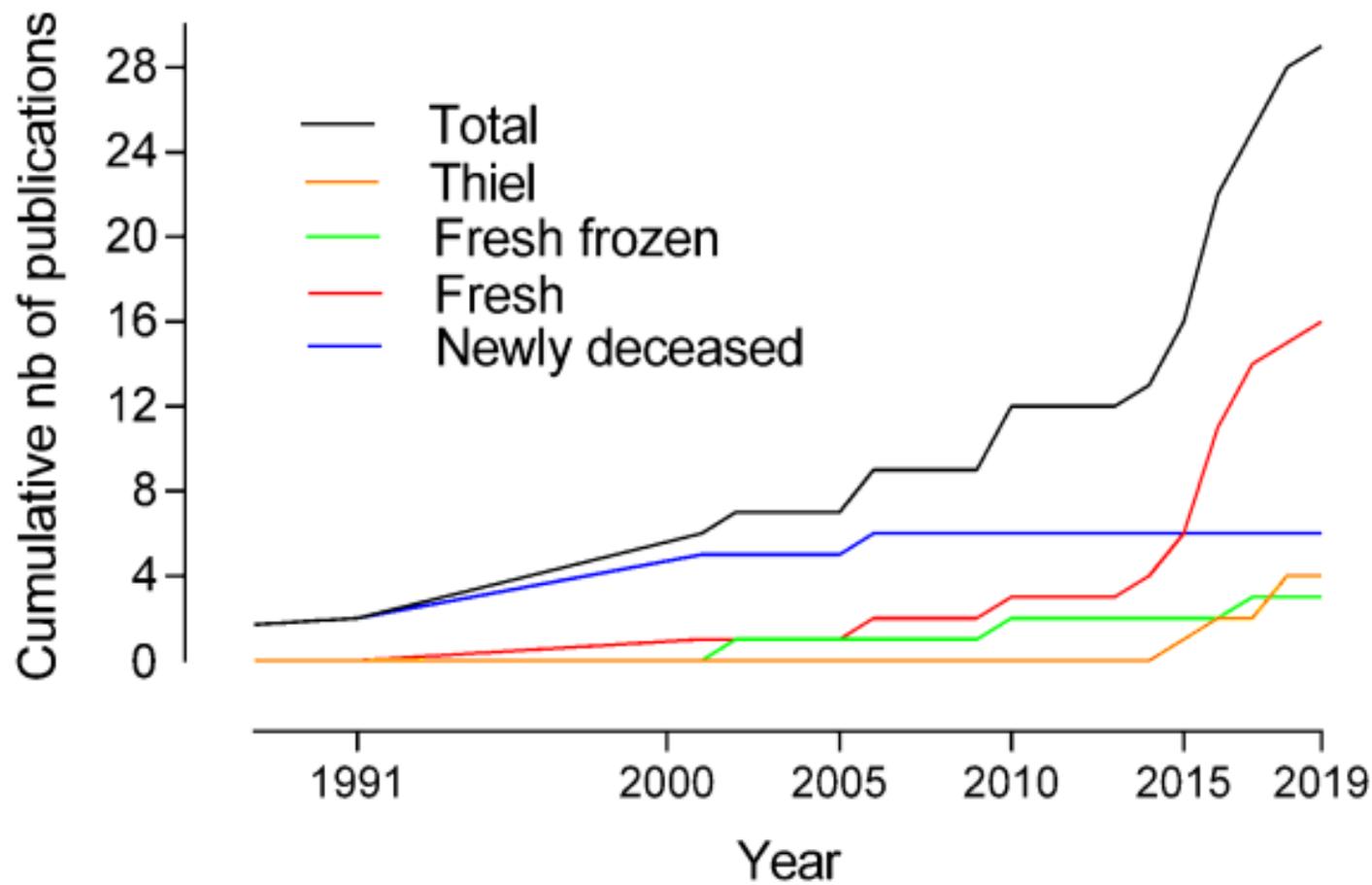


Eligibility



Included





**Table 1** - Models' description

<b>Type of cadavers</b>	<b>Preservative agents</b>	<b>Time between death and use</b>	<b>Storage</b>	<b>Period of use</b>
<b>Fresh</b>	None	A few hours (less than 72h usually)	4°C	Days
<b>Fresh-frozen</b>	None	Days	Ca.-18°C	Days
<b>Thiel-embalmed</b>	Glycol, various salts, boric acid, chlorocresol, formaldehyde, alcohol	A few months (immersion time)	20°C	Years
<b>Newly deceased</b>	None	Immediately after death	None	Hours
<b>Formalin-embalmed</b>	Formaldehyde+/- phenol and glycerine	Hours	20°C	Years

**Table 2 – Domains of study**

	<b>Fresh</b>	<b>Fresh-frozen</b>	<b>Thiel-embalmed</b>	<b>Newly deceased</b>
<b>Ventilation and airways' management</b>	<i>Truszewski et al.</i> <i>Truszewski et al.</i> (2) <i>Cho et al.</i> <i>Segal et al. (2)</i> <i>Coats et al.</i> <i>Piegeler et al.</i> <i>Ruetzler et al.</i>	<i>Silvestri et al.</i>	<i>Charbonney et al.</i> <i>Grieco et al.</i> <i>Savary et al.</i>	<i>Davis et al.</i> <i>Langhelle et al.</i> <i>Lufkin et al.</i>
<b>Haemodynamics</b>	<i>Moore et al.</i> <i>Rutty et al.</i>			<i>Wei et al.</i> <i>Rieder et al.</i> <i>Skinner et al.</i>
<b>Thoraco(s)tomy</b>		<i>Hanouz et al.</i>	<i>Puchwein et al.</i>	
<b>Mechanical properties of the chest</b>	<i>Segal et al.</i> <i>Baubin et al.</i> <i>Eichhorn et al.</i>	<i>McKay et al.</i>		
<b>Defibrillation safety</b>	<i>Wampler et al.</i> <i>Lemkin et al.</i>			
<b>Bispectral index monitoring</b>	<i>Fatovich et al.</i>			
<b>Intraosseous access</b>	<i>Szarpak et al.</i>			

References	CC	Ventilation	Perfusion/ declotting	Equipment	Number of cadavers	Age (mean+/- SD)	Weight	Post-mortem interval (in hours)
<i>Truszewski et al.</i>	Automated	No	No	ETI	10	18-25 <sup>a</sup>	UK	up to 72
<i>Charbonney et al.</i>	Manual + automated	Yes	Yes	ETI	11	81+/-9	63+/-13	UK
<i>Szarpak et al.</i>	Automated	No	No	IOD	42	18-65 <sup>a</sup>	UK	up to 72
<i>Wampler et al.</i>	Manual + automated	No	No	ECG	2	UK	UK	UK
<i>Rieder et al.</i>	Manual	UK	No	Pressure catheters: ABP, SG	3	UK	UK	0
<i>Truszewski et al. (2)</i>	Automated	No	No	ETI	5	18-65 <sup>a</sup>	UK	up to 72
<i>Languelle et al.</i>	Manual	No	No	ETI	12	68+/-15	80+/-15	0
<i>Cho et al.</i>	Manual	Yes	No	ETI	1	UK	UK	UK
<i>Fatovich et al.</i>	Manual	No	No	BIS monitor	1	58	UK	48
<i>McKay et al.</i>	Manual	No	No	Sternal plates	6	UK	UK	UK
<i>Segal et al.</i>	Automated + ACD-ITD	No	No	No	9	75+/-17	66+/-16	72-96
<i>Baubin et al.</i>	ACD	No	No	No	36	74+/-24	63+/-25	22+/-28
<i>Puchwein et al.</i>	OCM	No	No	No	29	UK	UK	UK
<i>Moore et al.</i>	Automated	Yes	Yes	ETI + pressure catheters: AoP, ICP, ITP	9	84+/-10	70+/-14	89+/-48
<i>Rutty et al.</i>	Automated	No	Yes	No	14	74+/-17	UK	53+/-62
<i>Eichhorn et al.</i>	Automated	No	No	No	20	74+/-13	80+/-15	70+/-22
<i>Segal et al. (2)</i>	Automated	Yes	Yes	ETI + pressure catheters : ITP, ABP	7	UK	UK	UK
<i>Coats et al.</i>	Automated	Yes	No	ETI	1	UK	UK	32
<i>Silvestri et al.</i>	No	Yes	No	ETI + IOI + IOD	2	80	UK	36+/-12 <sup>b</sup>
<i>Ruetzler et al.</i>	Automated	Yes	No	Supra-glottic airway device	18	66+/-12	UK	UK
<i>Piegeler et al.</i>	Manual	Yes	No	Gastric tube	30	69+/-29	69+/-26	< 3
<i>Hanouz et al.</i>	No	No	No	No	10	UK	UK	UK
<i>Grieco et al.</i>	Automated	Yes	No	ETI + pressure catheter: ITP	3	73+/-7	68+/-12	UK
<i>Savary et al.</i>	Yes	Yes	Yes	ETI	2	UK	UK	UK
<i>Wei et al.</i>	Manual	No	No	Pressure catheter: ABP	11	59+/-11	65+/-9	0
<i>Lemkin et al.</i>	No	No	No	Defibrillation pads	8	UK	UK	UK
<i>Davis et al.</i>	No	Yes	No	Flow and pressure transducer in ETT	25	63+/-10	80+/-15	0
<i>Lufkin et al.</i>	Manual	Yes	No	Radial artery line	10	83	UK	0
<i>Skinner et al.</i>	Manual	Yes	No	ETI	7	UK	UK	0

**Table 3 – Studies’ characteristics**

CC, chest compression; UK, unknown; ACD, active compression-decompression; ITD, impedance threshold device; OCM, open cardiac massage; ETI, endotracheal intubation; IOD, intraosseous device; ECG, electrocardiogram; SG, swan-ganz; BIS, bispectral index; AoP, aortic pressure; ICP, intracranial pressure; ITP, intrathoracic pressure; ABP, arterial blood pressure; IOI, intraesophageal intubation; ETT, endotracheal tube

<sup>a</sup>Range

<sup>b</sup>Time between death and freezing was considered