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1 GASTRIC INSUFFLATION DURING CARDIOPULMONARY RESUSCITATION: A STUDY IN HUMAN
2 CADAVERS

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37 **Abstract: Introduction:**

38 Bag-valve-mask ventilation is the first-line ventilation method during cardiopulmonary
39 resuscitation (CPR). Risks include excessive volume delivery and gastric insufflation, the latter
40 increasing the risk of pneumonia. The efficacy of ventilation can also be reduced by airway
41 closure. We hypothesized that continuous chest compression (CC) could limit the risk of gastric
42 insufflation compared to the recommended 30:2 interrupted CC strategy. This experimental
43 study was performed in human "Thiel" cadavers to assess the respective impact of discontinuous
44 vs. continuous chest compressions on gastric insufflation and ventilation during CPR.

45 **Methods:**

46 The 30:2 interrupted CC technique was compared to continuous CC in 5 non-intubated cadavers
47 over a 6 minute-period. Flow and Airway Pressure were measured at the mask. A percutaneous
48 gastrostomy allowed measuring the cumulative gastric insufflated volume. Two additional
49 cadavers were equipped with esophageal and gastric catheters instead of the gastrostomy.

50 **Results:**

51 For the 7 cadavers studied (4 women) median age of death was 79 [74-84] years.
52 After 6 minutes of CPR, the cumulative gastric insufflation measured in 5 cadavers was markedly
53 reduced during continuous CC compared to the interrupted CC strategy: (1.0 [0.8-4.1] vs. 5.9
54 [4.0-5.6] L; $p < 0.05$) while expired minute ventilation was slightly higher during continuous than
55 interrupted CC (1.9 [1.4-2.8] vs. 1.6 [1.1-2.7] L/min; $P < 0.05$).
56 In 2 additional cadavers, the progressive rise in baseline gastric pressure was lower during
57 continuous CC than interrupted CC (1 and 2 cmH₂O vs. 12 and 5.8 cmH₂O).

58 **Conclusion:**

59 Continuous CC significantly reduces the volume of gas insufflated in the stomach compared to
60 the recommended 30:2 interrupted CC strategy. Ventilation actually delivered to the lung is also
61 slightly increased by the strategy.

62 **Keywords:** Cardio pulmonary resuscitation; Chest compression; Gastric insufflation; Esophageal
63 pressure

64

65 1. Introduction

66 Survival from out-of-hospital cardiac arrest depends on the rapid initiation of cardiopulmonary
67 resuscitation (CPR) and defibrillation to maintain perfusion to vital organs and promptly restore
68 spontaneous circulation(1). The importance of high-quality CPR is strongly emphasized by the
69 International Liaison Committee on Resuscitation but there is considerable debate around the
70 role of ventilation during CPR. Current guideline recommendations are to provide chest
71 compressions and bag-valve-mask ventilation in a 30:2 ratio for adult patients in the absence of
72 an advanced airway (2). Studies have not shown that performing continuous chest compressions
73 with regular, interspersed ventilation cycles resulted in improved outcomes(3,4).

74 While ventilation is critical for maintaining tissue oxygenation and CO₂ elimination, during
75 cardiac arrest, the metabolic demand is decreased due to a low cardiac output and peripheral
76 perfusion. Even if ventilation is necessary for prolonged resuscitation(5), excessive ventilation can
77 have a detrimental physiological effect and lead to adverse patient outcomes. Ventilating with
78 excessive pressure, volume, or rates can also result in gastric insufflation and increased
79 intrathoracic pressure, leading to decreased venous return and cardiac output(6,7). The efficacy
80 of ventilation can also be reduced by airway closure that was recently described in patients with
81 out of hospital cardiac arrest(8,9). Gastric gas insufflation may lead to regurgitation and results in
82 the occurrence of aspiration pneumonia or pneumonitis(10). We hypothesized that continuous
83 chest compressions (CC) could limit the risk of gastric inflation without impairing ventilation
84 compared to the recommended 30:2 interrupted CC strategy.

85 The objective of this study was to assess the impact of continuous CC on gastric insufflation and
86 effective ventilation during bag-valve-mask ventilation.

87

88 2. Materials and Methods:

89 **Human cadavers and set-up:** The human "Thiel" cadavers came from a specific donation program
90 of the anatomy laboratory of UQTR (Université du Québec à Trois-Rivières) and experiments
91 were conducted in accordance with Canadian regulations after approval from the local Research
92 Ethics Board (CER-14-201-08-03.17). The Thiel embalmed cadavers are the result of a special
93 preparation method that allows for preservation of the tissue elastic properties, flexibility, and

94 texture. In addition, the anatomy of the oropharynx and upper airway are especially well-
95 preserved and allow for realistic bag-valve-mask ventilation (11,12). The respiratory mechanic
96 characteristics as well as the similarity with out-of-hospital cardiac arrest (OHCA) patients,
97 including the presence of airway closure, have been previously described by Charbonney et al.(9).

98 **Initial preparation:** The cadavers were initially intubated and ventilated with a tidal volume of
99 6mL/kg predicted body weight, respiratory rate 10/min and a PEEP of 10cmH₂O as previously
100 described (9).

101 **Measurement and setup:** Respiratory system compliance and resistance were calculated after 30
102 minutes of ventilation by measuring airway pressure (P_{aw}) during end-inspiratory and end-
103 expiratory occlusion; the endotracheal tube was then removed in order to proceed with the
104 experiments. Flow and P_{aw} were measured at the mask using a Pneumotachograph (Fleisch n°3,
105 Lausanne, Switzerland) positioned proximally to the mask (or the endotracheal tube during initial
106 preparation) and connected to a Biopac module system (Goleta, CA, USA) for later processing
107 (Acknowledge 3.7.3, Biopac Systems, Goleta, CA). Volume delivered by each bag valve mask
108 ventilation was measured as the integral of inspiratory flow for the insufflated volume and
109 expiratory flow for the expired tidal volume.

110 Experiment 1: In 5 cadavers, a percutaneous surgical gastrostomy was performed in the anterior
111 wall of the stomach through a 5 cm midline laparotomy to introduce a cuffed endotracheal tube
112 (size #6) into the stomach cavity. The duodenum was not clamped. An airtight purse suture was
113 placed on the stomach and the abdominal wall was sutured in two layers. The end of the
114 endotracheal tube was connected to a spirometer (Wright Medical, Tennessee, USA) to measure
115 the cumulative gas volume in the stomach cavity for each of the two tested CPR procedures. The
116 amount of gas accumulated in the stomach was measured at one-minute intervals for a total of 6
117 minutes.

118 Experiment 2: In 2 cadavers, esophageal and gastric pressures were measured using an
119 esophageal and gastric balloon catheter during 3 minute-experiments of the two previously
120 tested strategies. No gastrostomy was placed in these cadavers.

121
122 **Different chest compression-ventilation strategies tested:** Each cadaver underwent 2 different
123 manual bag-valve-mask CPR strategies randomly applied during 6 minute-periods (experiment 1)
124 and during 3 minute-periods (experiment 2). The two tested strategies were as follows:

- 125 A. Interrupted CC and ventilation with a 30:2 (CC/ventilation) ratio
- 126 B. Continuous CC with two insufflations administered after every thirty chest compressions

127 In the interrupted CC arm, two successive bag-valve-mask ventilations not exceeding one second
128 each were delivered every 30 CC while temporarily pausing chest compressions. In the
129 continuous CC arm, two successive bag-valve-mask ventilations not exceeding one second each
130 were delivered every 30 CC without interrupting CC during ventilation.

131 In-between each period of CPR, the stomach was completely emptied through the gastrostomy
132 tube prior to initiating CPR. CPR was performed according to the following procedure. Bag mask
133 ventilation was performed by two operators with professional experience in CPR (DS and JCR)
134 throughout the entire experimental procedure using a two-person ventilation technique. A two-
135 handed mask seal was obtained by the first person while ventilation was administered by the
136 second operator. The mask used was a standard facemask (inflatable air cushion mask, ResMed,
137 Taiwan). Compression of the bag was performed cautiously, following guideline
138 recommendations. To standardize as much as possible bag compressions independently of the
139 procedure tested, the two operators were trained before the experiment during a period of
140 resuscitation mixing continuous and interrupted CC. In addition, a metronome (a 1 second light
141 flashing 2 times every 30 CC) was specifically adapted and used for rhythm and duration of bag
142 insufflations. The head of each cadaver was held in extension and an oropharyngeal airway was
143 inserted as recommended. Chest compressions were performed by two other operators with
144 experience in CPR (IRD and EC) according to international recommendations at 100-110/min with
145 personnel changes every two minutes. A metronome was used to maintain appropriate CC rate.

146 **Esophageal pressure measurement:** In the 2 additional cadavers, esophageal and gastric balloon
147 (Nutrivent, Mirandola, Italy) were positioned as previously described (13) in complement to the
148 tube position inside the stomach.

149 Opening pressure of the lower esophageal sphincter was assessed in 3 of the cadavers. After
150 intubating the corps directly into the esophagus, the stomach was insufflated by a ventilator at a
151 pressure incremented step by step from 0 to 25 cmH₂O. The volume insufflated at each step of
152 incremented pressure was noted. The pressure at which the insufflated volume increased
153 significantly (from 0 to greater than 50 ml) was considered as the critical pressure threshold
154 above which the oesophagus was open (opening pressure of the lower esophageal sphincter).

155
156 **Statistical analysis:** Variables are expressed as median [25th - 75th percentiles]. Differences
157 between variables across different data obtained for each strategy were tested by a non-
158 parametric signed-ranked test (Wilcoxon). A level of $p < 0.05$ was considered to be statistically
159 significant.

160

161 **3. Results**

162 For all the 7 cadavers tested (5 cadavers for experiment 1, and 2 for experiment 2), anthropic
163 characteristics and respiratory mechanics, including the level of airway closure, are listed in **Table**
164 **1.**

165 **Experiment 1 (5 cadavers):**

166 Number of insufflations, insufflation time, mean and maximal airway pressure (Mean P_{aw} and
167 Max P_{aw}), ventilation and insufflation per minute (MV_{insp} , MV_{exp} , $Insuffl_{gast}$) are listed in **Table 2.**
168 Ventilation was delivered at the same rate in both strategies. Gastric insufflation was observed in
169 all the 5 cadavers tested in all conditions, with an amount that depended on the conditions
170 tested.

171 After 3 minutes of CPR the cumulative volume of gas insufflated into the stomach was reduced

172 on average by 1.6 L and at the end of the 6 minutes of CPR by 4.9 L during continuous CC
173 compared to interrupted CC 0.4 [0.4-2.0] vs. 2.0 [1.9-2.3] L and 1.0 [0.8-4.1] vs. 5.9 [4.0-7.6] L;
174 $p=0.0002$; **figure 1**). Inspired ventilation was slightly but significantly lower, while expired
175 ventilation was slightly but significantly higher with continuous CC (**figure 2 & table 2**).

176 On average, the volume delivered by a single bag mask insufflation was lower during continuous
177 CC compared to interrupted CC (592 ± 99 mL vs 722 ± 111 mL). Bag mask insufflations were
178 characterized by an identical amount of leaks between the two strategies (26% vs. 26%) but the
179 distribution of insufflated gastric volume and expired volume was different (respectively 11% vs.
180 26% and 63% vs. 48%) during continuous CC compared to interrupted CC as shown in **figure 3**.

181
182 The opening esophageal pressure, measured as described above in 3 cadavers, was 15, 16, and
183 19 cmH₂O respectively.

184

185 **Experiment 2 (2 cadavers):**

186 The changes in baseline gastric pressure (ΔP_{gas}) over the 3 minutes induced by gastric insufflation
187 were measured in 2 cadavers during the 2 strategies tested: it amounted to respectively 12.0 and
188 5.8 cmH₂O during interrupted CC but only 1.0 and 2.0 cmH₂O during continuous CC (**figure 4**).

189 Esophageal pressure swing due to chest compressions was not significantly different during
190 continuous CC compared to interrupted CC ($11.7 [5.3-20.1]$ vs. $12.8 [6.0-20.5]$ cmH₂O; $p=0.49$).

191 **Discussion:**

192 **Main findings:**

193 Our study shows that continuous CC significantly reduced the volume of gas insufflated in the
194 stomach compared to the recommended 30:2 interrupted CC strategy. In addition, continuous
195 CC do not impair the amount of ventilation actually delivered to the lungs during manual bag-
196 mask-ventilation.

197 **Impact of continuous CC on gastric insufflation and ventilation**

198 The risk of hyperventilation associated with manual bag ventilation during resuscitation has been
199 extensively documented(14,15). The associated risk of gastric regurgitation is also well
200 described(16,17). Previous observations suggest that even moderate, gastric distension
201 generated by manual bag insufflation may affect both CPR attempt and post-resuscitation
202 care(18,19). The most commonly recognised complication of gastric insufflation is regurgitation
203 of gastric content. In a recent large randomized controlled trial, the incidence of clinically
204 observed gastric regurgitation during conventional 30:2 bag mask ventilation reached 15,2% of
205 CPR attempts(20). Several experiments have tried to analyse whether the peak or the duration of
206 airway pressure above the lower esophageal sphincter opening pressure is mainly responsible of
207 gastric insufflation(16,21). Unfortunately, these studies evaluated gastric inflation only during
208 interrupted CC in models far from the physiological conditions of a real cardiac arrest patient
209 (7,22,23). The substantial amount of gastric insufflation reported in the present study during the
210 30:2 strategy is high but consistent with findings already obtained in a cadaver model(24). In this
211 study, the authors demonstrated that continuous CC associated with continuous flow insufflation
212 (generating positive pressure with no additional bag ventilation) significantly reduced gastric
213 insufflation compared to the conventional bag mask 30:2 interrupted chest compression
214 strategy. Bag insufflation associated with continuous flow insufflation was not tested, however,
215 and this study did not permit to distinguish the sole effect of continuous CC irrespective of
216 insufflation. The authors concluded that gastric distension was essentially due to the high airway
217 pressure resulting from bag insufflation rather than the effect of CC per se. Unfortunately,
218 insufflated volume and airway pressure were not measured in that study.

219 In the present study, we demonstrate that for a similar ventilation strategy (2 insufflations every
220 30 CC), continuous chest compression significantly reduces gastric insufflation, whether it is
221 quantified per minute or cumulatively. Continuous CC allows for the redistribution of gastric
222 insufflation to lung ventilation despite the expected overall reduction of insufflated volume
223 delivered by the bag. The optimal level of lung ventilation including the potential contribution of
224 CC-induced ventilation is still a matter of debate which the present experiment did not address.

225

226 **Physiological interpretation of the results**

227 The fact that continuous CC significantly reduces gastric distension without impairing lung
228 ventilation could seem counterintuitive at first sight. These findings can be explained by the
229 physiological rules that govern gas motion entering and exhaling the respiratory system during
230 chest compressions.

231 The pressure at which the lower esophageal sphincter opens in alive patient during anaesthesia
232 has been estimated around 20 cmH₂O(6,10). The lower esophageal sphincter pressure has been
233 also measured before and immediately after death in a series of 3 patients using simple
234 manometry showing an opening pressure that decreased around 5 cmH₂O immediately after
235 death, thus suggesting that gas may easily inflate the stomach during positive pressure
236 ventilation in cardiac arrest patients(25,26). Interestingly, we determined in 3 cadavers the lower
237 esophageal sphincter opening pressure by specifically assessing the pressure at which gas starts
238 to enter into the stomach and we found significantly higher values. This apparent inconsistency
239 may be explained by the fact that conventional manometry assessing the pressure in the
240 esophagus may underestimate the pressure needed to push gas along the entire esophageal
241 length. This hypothesis explains why not only the exceeding pressure above the theoretical
242 esophageal opening pressure but also the time during which this pressure is applied in the
243 oropharynx has been identified as the two distinct mechanisms explaining gastric insufflation
244 during bag mask ventilation(16,21). Despite the relatively high lower esophageal opening
245 pressure observed in our model, the exceeding pressure above oesophageal opening pressure
246 delivered along the 1 second insufflation time explain the substantial amount of gastric
247 insufflation reported during the 30:2 interrupted CC strategy (see figure). In addition the recently

248 described phenomenon of intrathoracic airway closure that has been shown to impede lung
249 ventilation may also have facilitated gastric insufflation(27,28). In fact, this unrecognized
250 phenomenon may tend to redistribute gas from the trachea to the esophagus in non-intubated
251 patients.

252

253 **How continuous CC can limit gastric insufflation without impairing ventilation?**

254 During a 1 second bag insufflation, 2 CC occur on average, i.e., meaning 2 compressions and
255 decompressions. The pressure applied on the sternum during CC increases intrathoracic and
256 esophageal pressure and as a result tends to collapse the lungs and close the esophagus. In other
257 words, physiologically, the higher the pressure generated by CC, the lower the lung and
258 esophageal distending pressures. Both lung and esophageal insufflations are significantly
259 impeded during CC. During decompression, intrathoracic pressure suddenly decreases due to
260 thoracic recoil pressure and as result aspirates gas pushed by the bag inside the bronchial tree
261 and the lung thus favouring lung ventilation. In contrast, duration of decompression is too short
262 to permit positive bag pressure to reopen the esophagus, which is a virtual lumen previously
263 collapsed by CC. Thus, CC impedes both lung and gastric insufflation while decompression
264 increases transpulmonary pressure and lung ventilation but not gastric insufflation. Recordings of
265 pressure generated by the bag and pleural pressure illustrated in the **figure 4** highlight this
266 mechanism.

267

268 **Clinical implications:**

269 The main rationale for interrupted 30:2 CC ventilation ratio before advanced airway placement is
270 that continuous CC may jeopardize bag ventilation and favour gastric regurgitation by increasing
271 airway pressure (32). The rationale supporting this recommendation is weak and the physiological
272 impact of continuous versus interrupted CC on both ventilation and gastric insufflation has never
273 been specifically investigated. Nevertheless, despite animal and human studies demonstrating
274 the benefit of continuous CC on circulation a recent large RCT has failed to demonstrate a benefit
275 on outcome of a systematic continuous CC strategy compared to the interrupted CC strategy(29–
276 31). Regurgitation was not systematically assessed in this study. Interestingly, the advantage of

277 continuous CC over interrupted CC regarding dispatch guided CPR and simplicity for CPR is
278 strong(30). The observations reported in the present study suggest (taking in to account the
279 methodological limits of the experiment) that continuous CC do not affect ventilation during bag
280 mask ventilation and significantly limit the risk of gastric insufflation thus suggesting that this
281 strategy is feasible.

282

283

284 **Limitations**

285 Some limitations of our study deserve to be discussed. First, the cadaveric model is not entirely
286 comparable to a real cardiac arrest patient. However, the lower esophageal opening pressure
287 reported in the present study is higher than previously described immediately after death(25,26)
288 and this may have interfered with our results by limiting gastric insufflation. Second, the method
289 we used to assess gastric insufflation along time, previously reported by Segal et al. (24)(i.e., a
290 surgical gastrostomy) may have limited stomach distension because the gastrostomy works as a
291 leak, and result in a lower impact on ventilation. However, our additional experiment preserving
292 the integrity of the stomach shows consistent result by directly measuring gastric pressure
293 change. Third, investigators could not be blinded, which may have influenced both CC and
294 ventilation. To limit this potential bias, the two investigators performing bag ventilation were
295 managed by a third investigator (for rhythm and bag compression) independently of the two
296 investigators performing CC who followed a specific metronome. Regarding bag ventilation a
297 specific training was performed before the experiment to standardize bag compression (strength
298 and duration) during interrupted and continuous CC. The fact that the experiment was limited to
299 6 minutes in our study might have favoured the quality of the ventilation while a longer duration
300 usually observed in real conditions tends to limit the attention of the rescuers and as results the
301 quality of bag-mask ventilation. Last, in the present experiment we did not measure the potential
302 contribution of CC-induced ventilation, which may have contributed to increase slightly actual
303 ventilation.

304 **Conclusion:**

305 During bag-valve-mask ventilation, continuous chest compressions significantly reduce the
306 quantity of gas insufflated into the stomach and increase lung ventilation compared to 30:2
307 interrupted CC strategy.

308

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313

314

315 Adding references

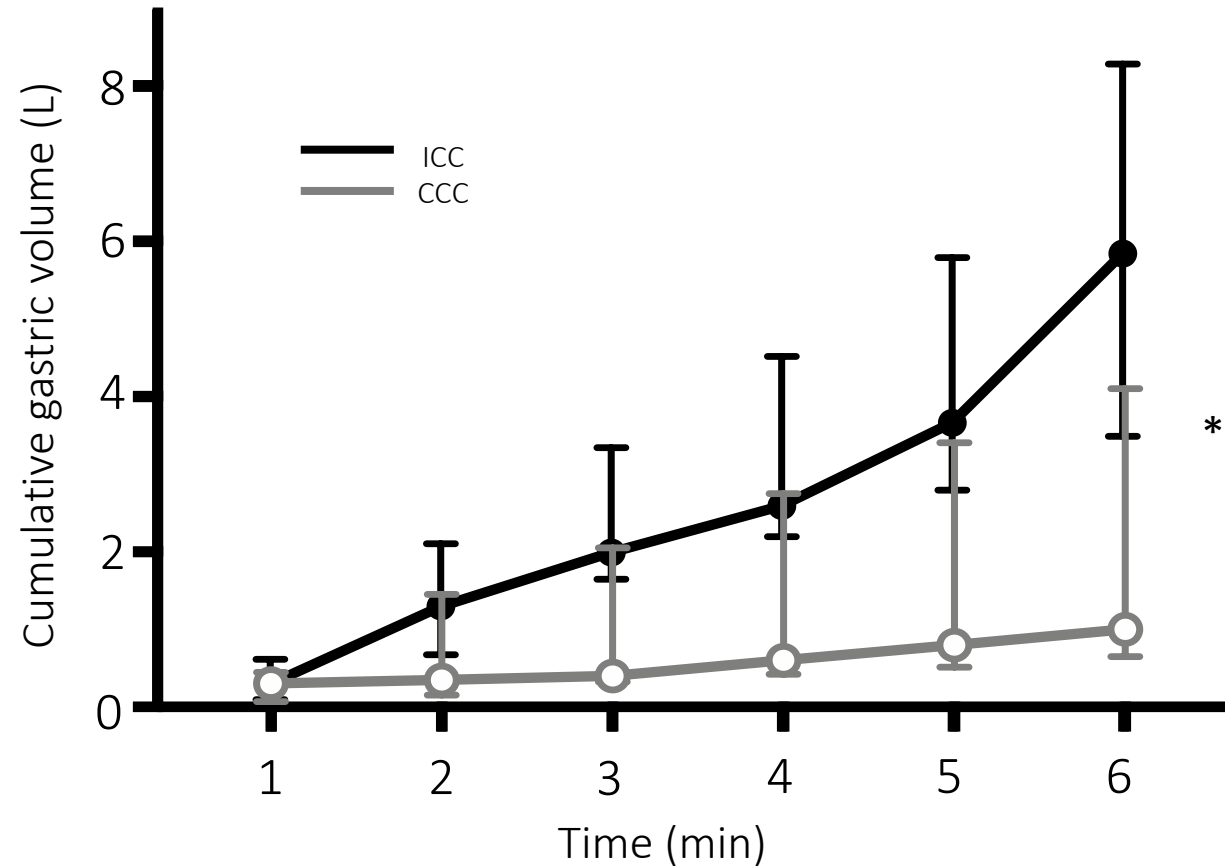
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Main figures

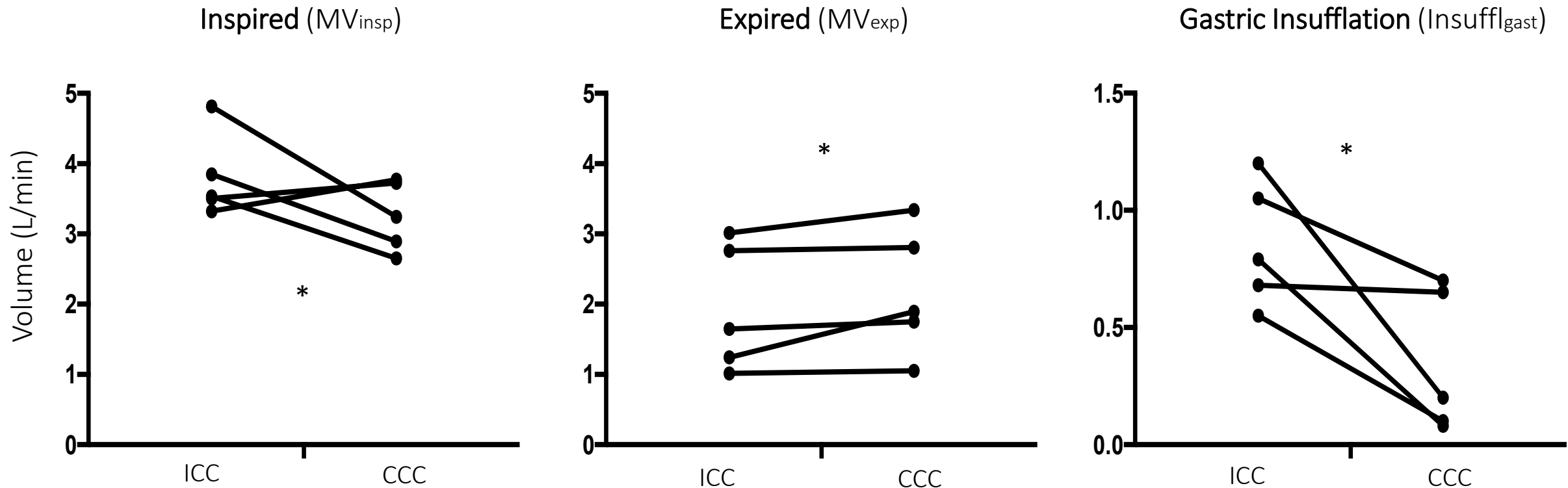
Fig. 1: Volume of gas insufflated in the stomach during resuscitation.



This figure shows the cumulative gastric insufflation, along the six-minutes resuscitation. Gastric insufflation was significantly higher in the interrupted CC resuscitation compared the continuous CC strategy.

ICC: interrupted chest compression; CCC: continuous chest compression

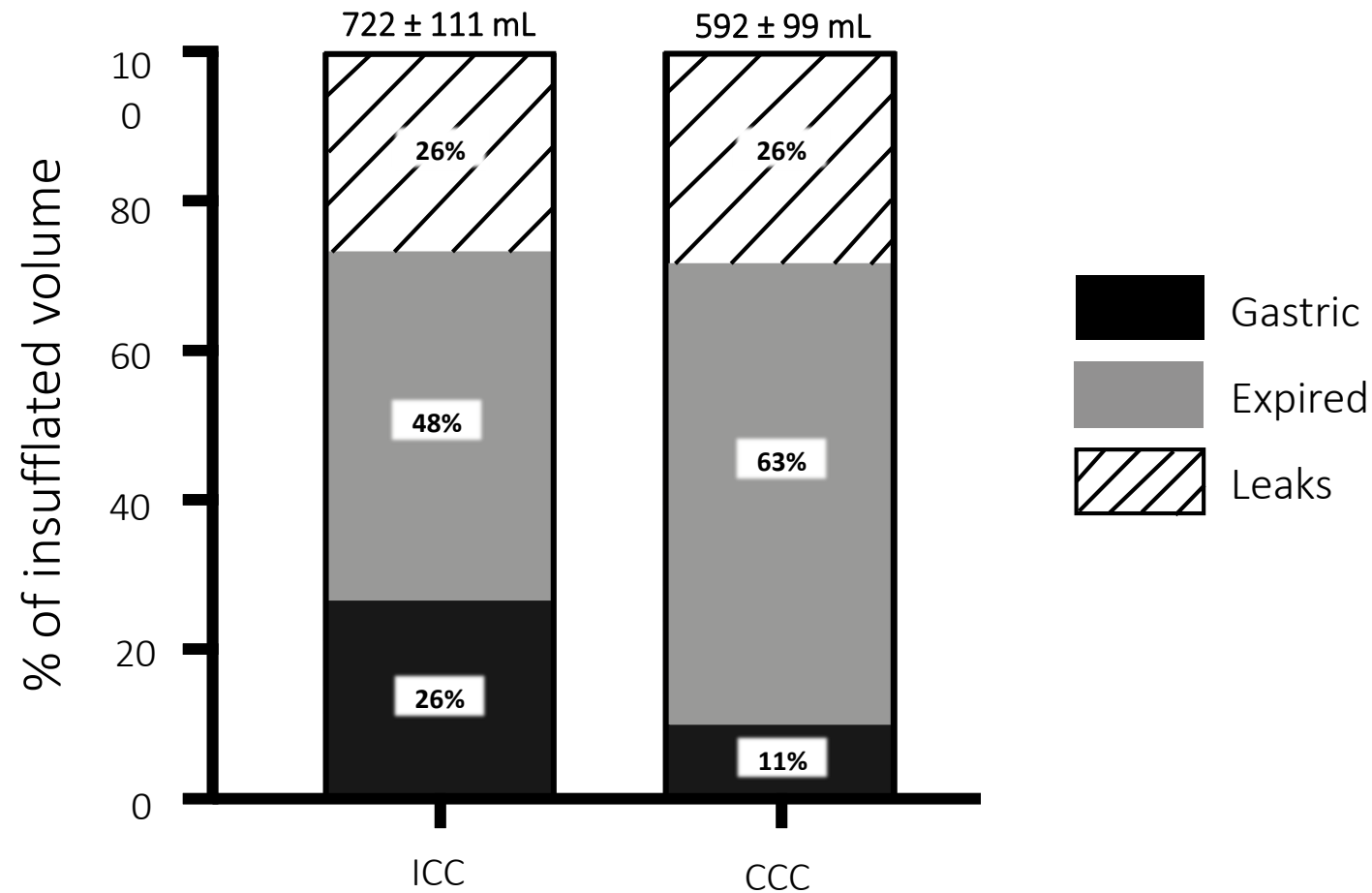
Fig. 2: Individual values of ventilation and gastric insufflation expressed per minute during resuscitation.



This figure shows individual values per minute for mean inspired and expired ventilation, and gastric insufflation, measured during the two 6 min strategies. Gastric insufflation was observed in all corpses, and all cadavers (except one) have a diminution of gastric insufflation in continuous CC strategy compared with the interrupted CC strategy. Continuous CC significantly impaired and reduced inspired ventilation while it slightly significantly increased expired ventilation compared to interrupted CC.

ICC: interrupted chest compression; CCC: continuous chest compression

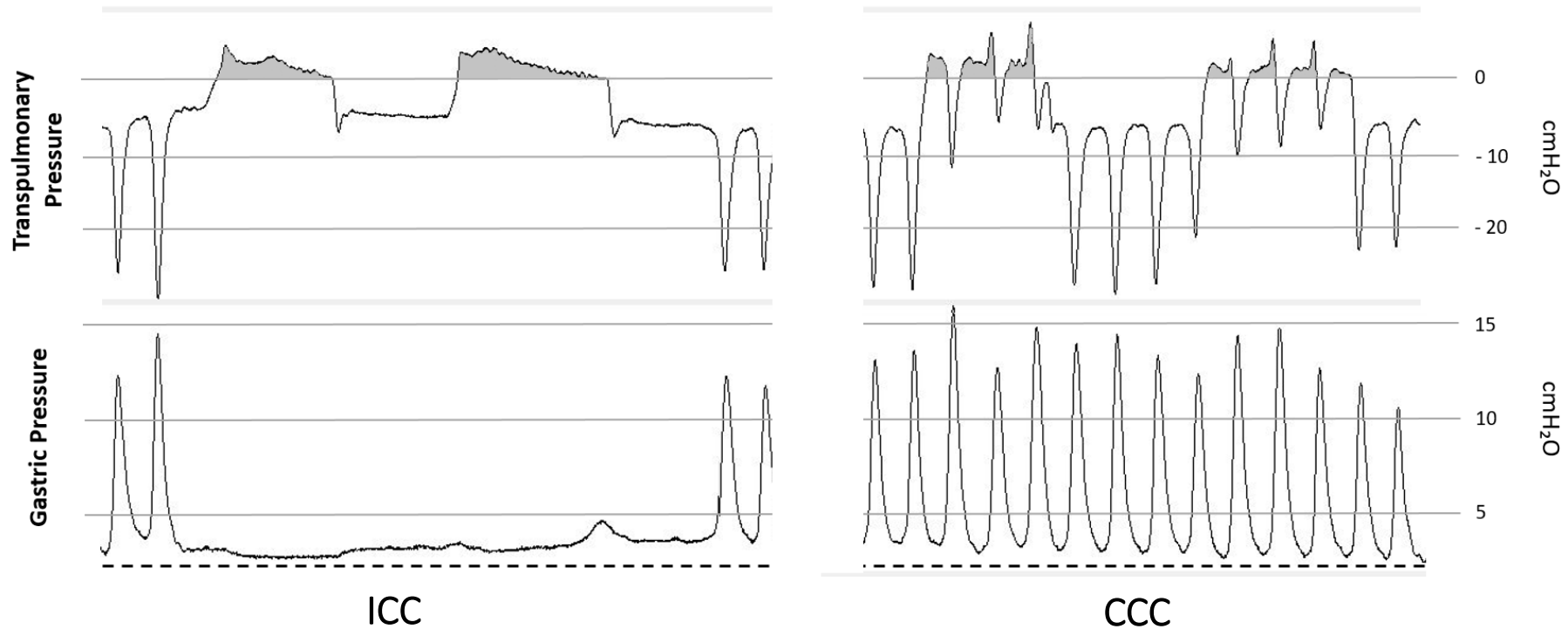
Fig. 3: Repartition of inspired volume delivered by one bag mask insufflation.



This figure shows expired ventilation, gastric insufflation, and leaks volumes expressed as percentage of a mean bag mask ventilation. Leaks were estimated from mean volumes for a single insufflation as “Leaks = $VT_{insp} - (VT_{exp} + V_{gast})$ ”.

ICC: interrupted chest compression; CCC: continuous chest compression

Fig. 4: Pressure tracings during bag mask insufflations.



This figure illustrates, transpulmonary pressure ($P_{aw} - P_{es}$), and gastric pressure tracings recorded in the two additional corps (experiment 2) during two bag mask insufflations for both resuscitation strategies. Gastric insufflation is driven by transpulmonary pressure according to a peak of pressure and a time effect. During continuous CC, each CC occurring during bag insufflation tends to suddenly reduce transpulmonary pressure and close esophagus. As result, the time during which positive transpulmonary pressure may insufflate the stomach is reduced, during continuous CC thus explaining the significant reduction of stomach insufflation. This result is illustrated by the increase of the baseline after the two insufflations during interrupted CC, while there is no increase of the baseline in continuous CC, suggesting less volume into the stomach during the continuous CC compared to interrupted CC strategy. *ICC: interrupted chest compression; CCC: continuous chest compression*

Tables

Table 1 : Anthropic characteristics and respiratory mechanics of the corps.

Corps	Experiment	Sex	Death	Age of death	Height (cm)	Weight (Kg)	C_{rs} (mL/cmH ₂ O)	Res (cmH ₂ O/L/s)	Airway closing pressure (cmH ₂ O)
#1	1	F	Arrhythmia	63	160	63.5	23.5	12	5
#2	1	F	Myocardial infarction	78	154	66	40	12	12
#3	1	M	Cancer	69	178	86	40	16	5
#4	1	F	Heart failure	86	150	54	45	14	7
#5	1	M	Cancer	79	165	73	44	10	5
#6	2	F	Stroke	91	152	37	38	15	4
#7	2	M	Kidney Failure	82	170	76	27	15	10
Median [25th-75th percentiles]				79 [74-84]	160 [153-169]	70 [57-75]	40 [39-43]	15 [13-15]	6 [5-9]

Table 2: Insufflations data and volumes per minute for the two tested strategies.

		Continuous CC	Interrupted CC	P values
Insufflations	Per minute	5.7 [5.0-5.7]	5.3 [5.3-5.3]	0.25
	Time (sec)	0.8 [0.7-1.0]	0.9 [0.7-1.1]	0.75
Pressure (cmH ₂ O)	Mean P _{aw}	24.6 [21.5-27.5]	25.5 [21.4-28.4]	0.27
	Max P _{aw}	36.8 [33.2-39.2]	35.3 [31.3-38.1]	0.05
Minute ventilation/insufflation (L/min)	MV _{insp}	3.4 [2.8-3.7]	3.6 [3.5-4.0]	0.0047
	MV _{exp}	1.9 [1.4-2.8]	1.6 [0.2-2.7]	0.001
	Insuffl _{gast}	0.2 [0.1-0.7]	0.7 [0.4-1.3]	0.001