Relationship between the regurgitated and the aspirated volume of water. A manikin study

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Abstract

Background: The relationship between gastric fluid volume, volume of fluid regurgitated, and aspirated fluid volume remains unclear. Using a life-like manikin suitable for a pulmonary aspiration model, we aimed to assess the relationship between regurgitated and aspirated clear fluid volumes, and to determine the minimal value of the volume of liquid regurgitated that may lead to pulmonary aspiration of fluid volume ≥ 0.8 mL kg^{-1} (around 60 mL) that is likely to cause lung injury.

Methods: Several volumes of water ranging from 30 to 150 mL were injected in a randomized order, at a flow rate of 20 mL per second, into the esophagus of a manikin lying in the supine position on a non-tilted table, with the manikin head in the extension or in the sniffing position. Aspirated volumes were measured in the manikin bronchi, by an investigator blinded to the volume injected. Aspiration was defined as positive when the volume of collected water was ≥ 60 mL for at least one of the five injections of each volume of water.

Results: The minimal volume of water injected into the esophagus for an aspirated volume ≥ 0.8 mL kg^{-1} was 85 mL in the sniffing position, and was 150 mL in the extension position.

Conclusions: These results suggest that the critical cut-off value of gastric fluid volume to be considered for the risk of significant pulmonary aspiration would be ≥ 85 mL (≥ 1 mL kg^{-1}), in the sniffing position. These results should however be confirmed in further studies using other models.

Key words: anesthesia, general, gastrointestinal contents, aspiration, manikin.

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Pulmonary aspiration of gastric contents is one of the most feared complications related to general anesthesia, which may be related to regurgitation or vomiting mainly at induction of anesthesia. Three conditions should be met for pulmonary aspiration to occur: increased gastric content volume, decreased lower esophageal sphincter pressure, and loss of protective airway reflexes. The latter two conditions are common during general anesthesia, and the increase in the gastric content volume may be minimized by following preoperative fasting guidelines that are currently recommended. Inadequate anesthetic technique leading to coughing/straining, with prolonged laryngoscopy and repeated attempts at intubation, also plays a critical role in the occurrence of regurgitation and aspiration.

Ultrasound examination of the gastric antrum has been recently described and validated for the preoperative assessment of gastric contents and volume [5–8]. In particular, the ultrasound measurement of the antral cross-sectional area in the right lateral decubitus position allows the calculation of gastric fluid volume [7], but the critical value of the gastric fluid volume enabling discrimination between high and low risk of aspiration remains controversial [9]. Current data from animal studies suggest that aspiration of gastric fluid volume ≥ 0.8 mL kg^{-1} and/or the presence of solid particles may lead to clinical consequences related to pulmonary aspiration. Nevertheless, the relationship between such aspirated fluid volume and regurgitated gastric fluid volume remains unknown, mainly because of the impossibility to perform an experimental study on humans addressing this issue [9].

Life-like manikins designed for teaching and training of airway management may also be used as a pulmonary aspiration model [11, 12]. Using such a manikin, we performed a study that aimed to

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assess the relationship between the regurgitated clear fluid volume and the aspirated clear fluid volume, and to determine the minimal volume of liquid regurgitated or vomited that leads to pulmonary aspiration of fluid volume ≥ 0.8 mL kg^{-1} (i.e. ≥ 60 mL for a 75-80 kg adult patient). A second aim of this study was to compare the volumes of fluid aspirated into the manikin trachea whether the head of the manikin was in the extension or in the sniffing position.

METHODS

Study protocol

This study did not require any approval from the local ethics committee because it did not involve human subjects.

The adult airway management trainer (Laerdal Ltd, Stavanger, Norway) manikin was used. The upper airway structure of this life-like manikin is watertight and separated from the esophagus as in humans (Figure 1). A previous analysis of the anatomical characteristics of the manikin upper airways concluded that this manikin is appropriate for use as a patient simulator for a pulmonary aspiration model. The distance between the corner of the mouth and the carina is 26 cm and the angles between a vertical line and the right and the left bronchus are 25° and 45°, respectively, similarly to adult humans.

The manikin was placed in the supine position on a non-tilted table. The head was either extended without a pillow (extension position), or extended and placed on a pillow 6 cm in height (sniffing position).

A 2-way Foley urinary catheter was inserted into the lower extremity of the esophagus of the manikin (at the level of the lower esophagus sphincter), and the balloon at the catheter tip was maximally inflated to prevent any backflow of the injected water through the catheter to the manikin stomach. Right and left manikin bronchi were each connected to a bottle to collect aspirated water (Figure 2).

For each head position, the following volumes of water were injected into the urinary catheter connected to the esophagus tube: 30, 60, 70, 85, 100, 120, and 150 mL. For a 30-year-old adult of height 175 cm and body mass 80 kg (as given by the manufacturer of the manikin), these volumes correspond approximately to 0.4, 0.8, 0.9, 1.1, 1.25, 1.5, and 1.9 mL kg^{-1}. Syringes of 60 mL with a conical tip (Pentaferte, Campli, Italy) were used to inject water with a flow rate of 20 mL per second. These volumes were each manually administered by an investigator (LB) on 5 occasions; this was done for each head position and the order of volumes injected was randomized using a computer generated list.

The volume of water that was collected in each bottle connected to each manikin bronchus was measured and recorded by a second investigator (EC) who was blinded to the volume injected. For each head position, aspiration into the bronchi was defined as positive when the volume of collected water was ≥ 60 mL for at least one of the five injections of each volume of water.

After each injection, the manikin was turned over so that the stagnant water could be totally evacuated from the manikin. The volume of water that was expelled from the mouth during each injection and the volume of water evacuated from the manikin between each experience were not measured.

Statistical analysis

Collected volumes were expressed as median (IQR [range]) and were compared using the Mann-Whitney *U* test and Wilcoxon signed rank test, as appropriate. The correlations between the injected volume and the collected volume were analyzed using

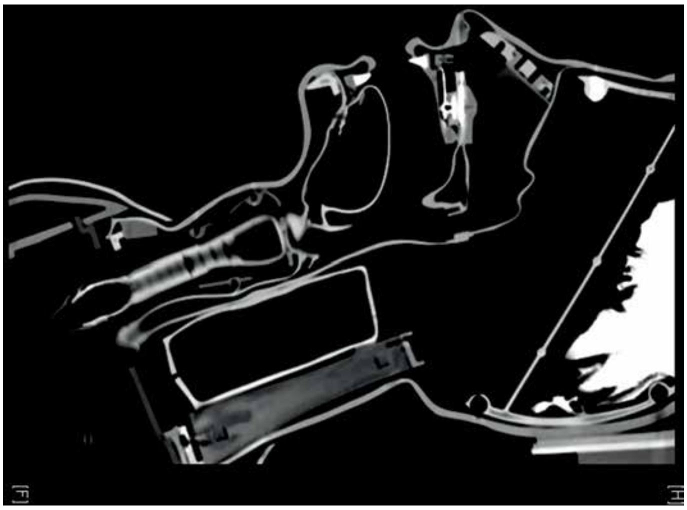

FIGURE 1. Sagittal scanner view of the head of the adult airway management trainer manikin used in this study

FIGURE 2. Experimental setup of the manikin

linear regression, with calculation of the corresponding Pearson correlation coefficients, for each head position. All analyses were performed using MedCalc version 12.1.4.0 for Windows (MedCalc Software, Ostend, Belgium) using a 2-sided type 1 error rate of 0.05 as the threshold for statistical significance.

RESULTS

Collected volumes according to injected volumes in the extension and sniffing positions are presented in Table 1. The median aspirated volume was 16 (0–51) mL in the extension position and 73 (48–108) mL in the sniffing position ($p < 0.0001$). When the head was in the extension position, aspirated volumes were all < 60 mL for injected volumes ranging from 30 to 120 mL, and aspirated volume was ≥ 60 mL in all cases for an injected volume of 150 mL. When the head was in the sniffing position, aspirated volumes were all < 60 mL for injected volume < 85 mL and aspirated volume was ≥ 60 mL in all cases for injected volumes ≥ 85 mL. Hence, the minimal volume of water injected into the esophagus for aspirated volume ≥ 60 mL (i.e. around 0.8 mL kg^{-1}) was 150 mL (i.e. around 2 mL kg^{-1}) in the extension position and 85 mL (i.e. around 1 mL kg^{-1}) in the sniffing position.

Aspirated volume was higher in the right bronchus than in the left bronchus, in both positions, as set out in Table 2. In the extension position, median aspirated volume was 15 (0–40) mL in the manikin right bronchus, vs. 0 (0–10) mL in the left bronchus ($P = 0.0022$). In the sniffing position, median aspirated volume was 59 (37–82) mL in the right bronchus vs. 15 (0–34) mL in the left bronchus ($P < 0.0001$).

The correlation between the injected volume and the collected volume was high in both positions; $r^2 = 0.89$ ($P < 0.001$) in the extension position, and $r^2 = 0.99$ ($P < 0.001$) in the sniffing position (Figure 3).

TABLE 1. Aspirated volumes of water in both positions (mL)

	Extension position	Sniffing position
30 mL	0 (0–0)	14 (13–15)
60 mL	0 (0–0)	47 (44–48)
70 mL	1 (0.9–2)	57 (56–58)
85 mL	16 (14–17)	73 (71–74)
100 mL	30 (27–31)	90 (87–91)
120 mL	55 (50–55)	109 (108–110)
150 mL	82 (80–82)	140 (139–141)

Data are expressed as median (range).

TABLE 2. Aspirated volumes of water in the right and left manikin bronchus for each position (mL)

	Extension position		Sniffing position	
	Right bronchus	Left bronchus	Right bronchus	Left bronchus
30 mL	0 (0–0)	0 (0–0)	14 (12–15)	0 (0–1)
60 mL	0 (0–0)	0 (0–0)	37 (35–37)	10 (9–11)
70 mL	1 (0.8–2)	0 (0–0)	47 (46–48)	11 (9–11)
85 mL	15 (13–15)	2 (1.5–2)	59 (56–59)	15 (14–15)
100 mL	26 (25–30)	2 (0–3.5)	69 (67–71)	20 (19–21)
120 mL	45 (41–45)	10 (10–10)	84 (82–84)	26 (25–26)
150 mL	66 (64–66)	15 (15–17)	108 (108–109)	31 (30–33)

Data are expressed as median (range).

DISCUSSION

The results of the present study show that a regurgitated fluid volume ≥ 85 mL (i.e. ≥ 1 mL kg^{-1}) was sufficient to lead to pulmonary aspiration of fluid volume ≥ 60 mL (i.e. ≥ 0.8 mL kg^{-1}) when the head of the manikin was placed in the sniffing position, while a much larger volume (≥ 150 mL) was required to lead to pulmonary aspiration of fluid volume ≥ 60 mL when placing the head in the extension position without a pillow.

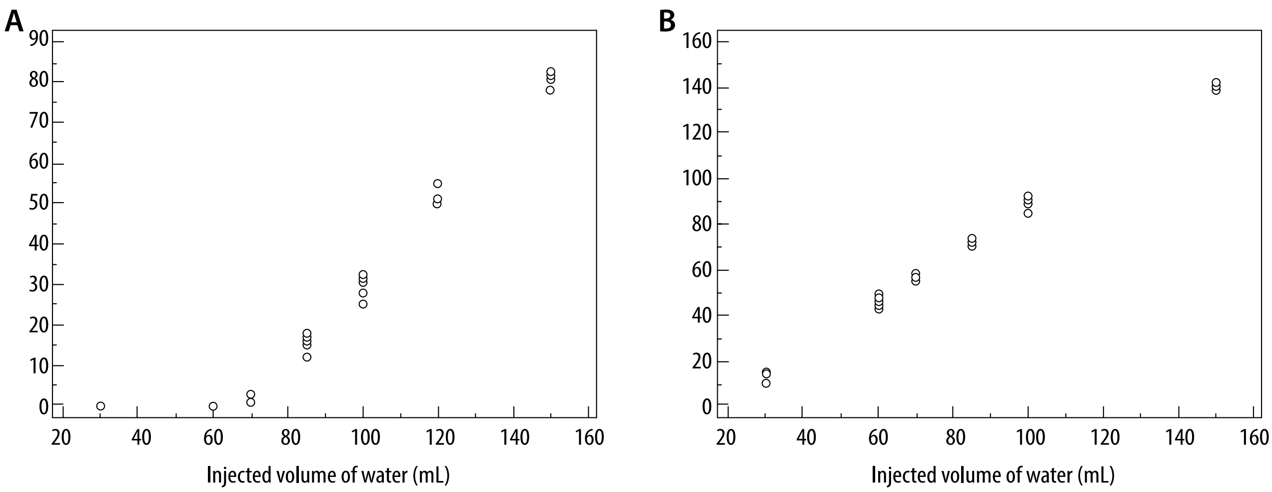

FIGURE 3. Correlation between the injected and the aspirated volume of water when the manikin head is in the extension position (**A**) and in the sniffing position (**B**)

The critical cut-off value of gastric fluid content associated with increased risk of pulmonary aspiration remains controversial. Roberts and Shirley first postulated that the critical volume of fluid aspirated into the trachea (i.e. leading to significant lung effects) may be around 0.4 mL kg^{-1}; however, this statement was based on unpublished data. Extrapolation of studies performed in monkeys suggests that the critical volume of acidic fluid for severe aspiration in adult humans would be around 0.8 mL kg^{-1} (i.e. 50 to 60 mL in an average adult). These definitions deal with the consequences of the direct tracheal injection of gastric fluid, without considering the relationship between gastric fluid volume, volume of fluid regurgitated, and volume of fluid aspirated into the trachea. Knowing the low incidence of pulmonary aspiration during general anesthesia, it can be assumed that the critical gastric fluid volume should be significantly larger than the basal fluid volume measured in elective fasted patients. In the current study, the minimal values of regurgitated fluid volume for aspiration of fluid volume ≥ 0.8 mL kg^{-1} into the lungs were much larger than the residual gastric fluid volumes previously suctioned in elective fasted patients, which ranged from 18 to 40 mL and were rarely > 100 mL. In particular, we previously reported that less than 3% of elective patients (vs. 68% emergency patients) had a gastric fluid volume ≥ 0.8 mL kg^{-1} [6]. Unfortunately, we could not assess the relationship between the gastric fluid volume and the regurgitated fluid volume. The only animal study assessing this relationship yielded results that cannot be extrapolated to humans [17]. This relationship may depend on the patient positioning and declivity, and on the mechanisms of regurgitation that may occur at induction of anesthesia. Active vomiting is probably more effective to propel gastric fluid content towards the esophagus than passive regurgitations related to the decrease in the lower esophageal sphincter pressure and/or to the cough-related increase in intra-abdominal pressure during laryngoscopy in case of inadequate anesthesia. Anyway, the regurgitated fluid volume is between part and the total gastric fluid volume; hence, the results of the present study suggest that gastric fluid volume ≥ 85 mL (around 1 mL kg^{-1}) or > 150 mL (around 2 mL kg^{-1}) according to the head position may potentially lead to significant pulmonary aspiration in case of regurgitation or vomiting at induction of anesthesia.

Cardio-pulmonary resuscitation is another particular situation at risk of regurgitation and aspiration. Chest compressions combined with positive pressure ventilation both lead to intermittent increased intrathoracic pressures favoring flow of gastric fluid contents towards the esophagus and ultimately to the trachea [18]. In human cadavers with gastric fluid volume of 500 mL, cardio-pulmonary resuscitation performed with the head in the extension position led to pulmonary aspiration in 40% to 60% of cases [18, 19]. The use of airway safety devices such as endotracheal intubation is therefore required to secure the airways and minimize the risk of aspiration during cardio-pulmonary resuscitation [19].

In the present study no fluid was expelled from the mouth, probably because of the low flow rate of injected water. The difference between the volumes of regurgitated and aspirated fluid is related to a "dead space effect" corresponding to the stagnation of liquid in the esophagus and in the pharyngeal cavity as long as the level of water is below that of the arytenoid cartilages. For each patient, this "dead space effect" is constant and depends mainly on his/her morphology, hence leading to the high correlations found between injected and collected volumes of water. The correlation between regurgitated and aspirated volumes was better in the sniffing position than in the extension position, and the aspirated volume was greater in the sniffing position. This may be related to the decrease in the "dead space" when the head is placed in the sniffing position, since elevating the manikin head in the sniffing position contributes to increase the mouth-arytenoid angle, hence favoring regurgitated clear fluids to flow back to the trachea.

The study does have some limitations. First, although anatomical characteristics of the manikin were close to those observed in humans, there are important differences, particularly with respect to the flexibility and rigidity of the tissues, which may have affected the results. In particular, the "dead space effect" may be somewhat different in the human. However, the manikin model remains of interest, since experimental studies assessing the part of regurgitated volume that is aspirated into the lungs are not feasible in the living human being. Such studies may be conducted in animals, but these models suffer from important differences as to the anatomical characteristics of the airway compared to humans, while the use of human cadavers also has its own limitations [18–20]. Another limitation was that the manikin was placed on a non-tilted table. Takaneka *et al*. previously reported that head-down tilt would be of interest to prevent aspiration, particularly when the head of the manikin was elevated for the sniffing position. Accordingly, 35° head-down tilt would have ensured complete prevention of aspiration in the extension position, without avoiding aspiration in the sniffing position. Nevertheless, to date, there is no firm recommendation as to the table tilt that should also ensure optimal intubation conditions in patients requiring rapid sequence induction. Finally, the results apply only to clear fluids, and would probably be different with thick fluids or with fluid containing solid particles. Ultrasound examination of the gastric antrum allows easy and rapid identification of thick fluids and solid contents, which should be considered as risk content for aspiration regardless of their volume. Conversely, ultrasound measurement of the antral cross-sectional area allows calculation of gastric volume for clear fluids; hence, the results of the present study may contribute to clarifying the interpretation of such calculations for the preoperative assessment of the risk of aspiration.

To conclude, the results of this study performed on a life-like manikin suggest that the regurgitation of at least 85 mL fluid would be sufficient to lead to significant aspiration of gastric fluid volume in patients lying on a non-tilted table with the head in the sniffing position, a particularly favorable position for laryngoscopy and intubation [21, 22]. Hence, the critical cut-off value of gastric fluid volume to be considered for the risk of significant pulmonary aspiration would be ≥ 85 mL (i.e. ≥ 1 mL kg^{-1}), in the sniffing position. These results should however be confirmed in further studies performed in animals or on human cadavers.

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