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Effects of decreasing inspiratory flow rate during simulated basic life support ventilation of a cardiac arrest patient on lung and stomach tidal volumes

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Abstract

If the airway of a cardiac arrest patient is unprotected, basic life support with low rather than high inspiratory flow rates may reduce stomach inflation. Further, if the inspiratory flow rate is fixed such as with a resuscitator performance may improve; especially when used by less experienced rescuers. The purpose of the present study was to assess the effect of limited flow ventilation on respiratory variables, and lung and stomach volumes, when compared with a bag valve device. After institutional review board approval, and written informed consent was obtained, 20 critical care unit registered nurses volunteered to ventilate a bench model simulating a cardiac arrest patient with an unprotected airway consisting of a face mask, manikin head, training lung [with lung compliance, 50 ml/0.098 kPa (50 ml/cmH_2O); airway resistance, 0.39 kPa/l/s (4 cmH_2O/l/s)] oesophagus [lower oesophageal sphincter pressure, 0.49 kPa (5 cmH_2O)] and simulated stomach. Each volunteer ventilated the model with a self-inflating bag (Ambu, Glostrup, Denmark; max. volume, 1500 ml), and a resuscitator providing limited fixed flow (Oxylator EM 100, CPR Medical devices Inc., Toronto, Canada) for 2 min; study endpoints were measured with 2 pneumotachometers. The self-inflating bag vs. resuscitator resulted in comparable mean $\pm$SD mask tidal volumes (945$\pm$104 vs. 921$\pm$250 ml), significantly ($P<0.05$) higher peak inspiratory flow rates (111$\pm$27 vs. 45$\pm$21 l/min), and peak inspiratory pressure (1.2$\pm$0.47 vs. 78$\pm$0.07 kPa), but significantly shorter inspiratory times (1.1$\pm$0.29 vs. 1.6$\pm$0.35 s). Lung tidal volumes were comparable (337$\pm$120 vs. 309$\pm$61 ml), but stomach tidal volumes were significantly ($P<0.05$) higher (200$\pm$95 vs. 140$\pm$51 ml) with the self-inflating bag. In conclusion, simulated ventilation of an unintubated cardiac arrest patient using a resuscitator resulted in decreased peak flow rates and therefore, in decreased peak airway pressures when compared with a self-inflating bag. Limited flow ventilation using the resuscitator decreased stomach inflation, although lung tidal volumes were comparable between groups. © 2002 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Bag valve mask; Cardiopulmonary resuscitation; Basic life support; Stomach inflation; Inspiratory flow rate; Peak airway pressure

Resumo

Se a via aérea de um doente em paragem cardíaca não estiver protegida, o suporte básico de vida com fluxos inspiratórios baixos em vez de altos pode reduzir a insuflação gástrica. Adicionalmente, se o fluxo inspiratório for constante, tal como ocorre num ventilador, o desempenho pode melhorar, principalmente quando usado por socorristas menos experientes. O objectivo deste estudo foi verificar o efeito da ventilação com fluxos limitados nas variáveis respiratórias e nos volumes pulmonar e gástrico quando comparado com um sistema de reservatório-valvula (autoinsuflador). Depois da aprovação da administração da instituição e da

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obtenção do consentimento informado, 20 enfermeiras de cuidados intensivos foram voluntárias para ventilar um modelo de doente em paragem cardíaca com a via aérea não protegida e que consistia numa máscara facial, cabeça de manequim, pulmão de treino [com compliance de 50 ml/0.098 KPa (50 ml/cmH_2O); resistência das vias aéreas de 0.39 KPa/l/s (4 cmH_2O/l/s)], esófago [pressão esfincter esofágico inferior de 0.49 KPa (5 cmH_2O)] e estomago simulado. Cada voluntário ventilou o modelo com um auto-insuflador (Ambu, Glostrup, Dinamarca; vol máx 1500 ml) e um ventilador que fornecia um fluxo fixo limitado (Oxylator EM 100, CPR Medical devices Inc, Toronto, Canada) durante 2 minutos; as variáveis do estudo foram medidas com 2 pneumotacometros. A comparação do auto-insuflador vs. ventilador gerou volumes correntes médios ± SD da máscara comparáveis (945 ± 104 vs. 921 ± 250 ml), fluxos no pico inspiratório significativamente mais elevados ($P < 0.05$, 111 ± 27 vs. 45 ± 21 l/min), e pressão inspiratória de pico também com diferença significativa (1.2 ± 0.47 vs. 78 ± 0.07 KPa), mas tempos inspiratórios significativamente mais curtos (1.1 ± 0.29 vs. 1.6 ± 0.35 s). Os volumes correntes pulmonares foram comparáveis (337 ± 120 vs. 309 ± 61 ml), mas os volumes correntes gástricos foram significativamente ($P < 0.05$) mais elevados (200 ± 95 vs. 140 ± 51 ml) com o auto-insuflador. Em conclusão, a ventilação simulada de um doente em paragem cardíaca não intubado, utilizando um ventilador, resultou numa diminuição dos fluxos de pico e, por conseguinte, em diminuição das pressões de pico das vias aéreas quando comparado com a utilização de um auto-insuflador. A ventilação com fluxos limitados utilizando um ventilador, diminuiu a insuflação gástrica apesar de os volumes correntes pulmonares serem comparáveis em ambos os grupos.

Palavras chave: Máscara insuflador; Ressuscitação cárdiopulmonar; Suporte básico de vida; Insuflação gástrica; Taxa de fluxo inspiratório; Pressão de pico das vias aéreas

Resumen

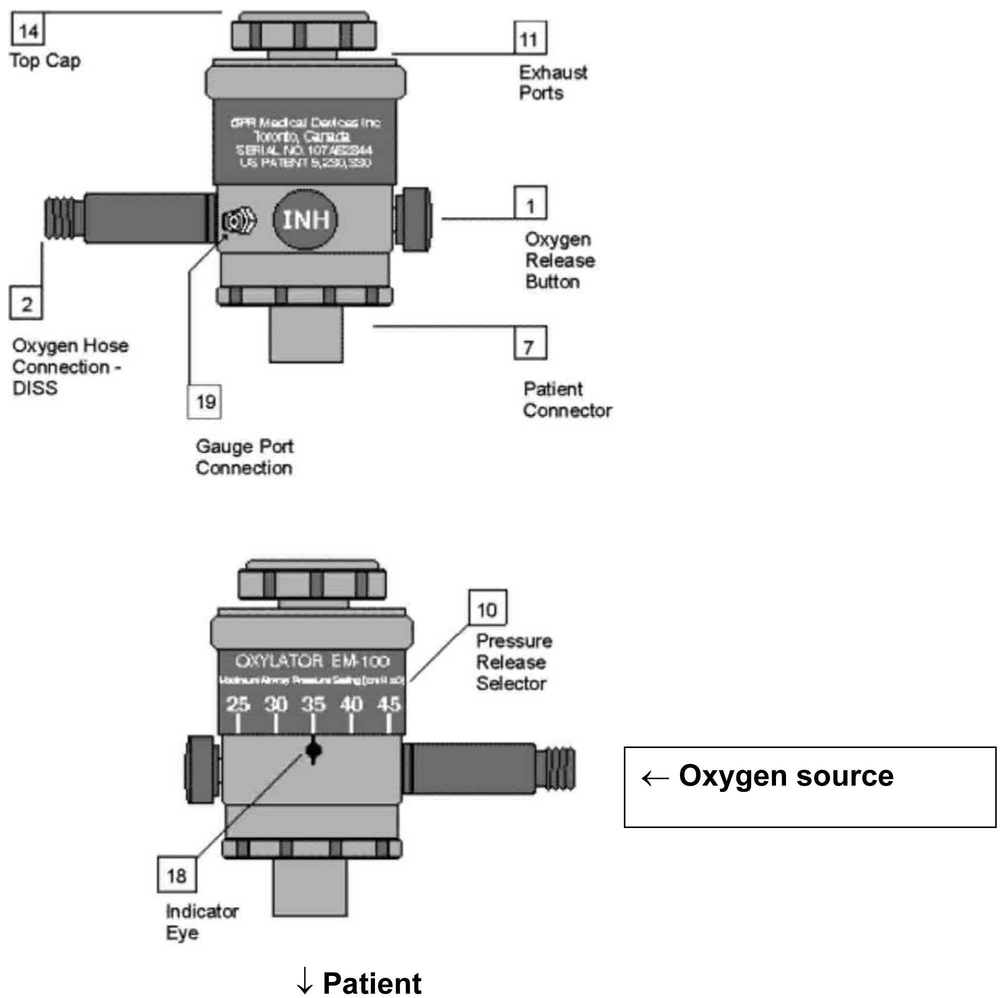
Si la vía aérea de un paciente no está protegida, el soporte vital básico usando flujos inspiratorios bajos en lugar de altos, puede reducir la insuflación gástrica. Mas aún, si el flujo inspiratorio está fijado, como al ventilar con el resucitador, el desempeño de la ventilación puede mejorar; especialmente cuando es usado por reanimadores menos experimentados. El propósito de este estudio fue evaluar el efecto de la ventilación con flujo limitado sobre las variables respiratorias y sobre los volúmenes pulmonares y gástrico, comparandolo con el de ventilación con dispositivo de bolsa con válvula. Después de la aprobación de la junta institucional de revisión, y de obtener un consentimiento informado escrito, 20 enfermeras registradas de cuidados intensivos se ofrecieron de voluntarias para ventilar un modelo que simula de paro cardíaco con vía aérea sin proteger, consistente en una máscara facial, una cabeza de maniquí, un pulmón de entrenamiento [con compliance pulmonar de 50 ml/0.098 kPa (50 ml/cmH_2O); resistencia de la vía aérea 0.39 kPa/l/s (4 cm H_2O/l/s)], esófago [presión del esfínter esofágico inferior, 0.49kPa (5cm H_2O)], y un estómago simulado. Cada voluntario ventiló el modelo con un dispositivo mascara-bolsa autoinflable con válvula, (Ambu, Glostrup, Denmark; volumen máximo, 1500 ml), y con un resucitador que proporciona un flujo fijo limitado (Oxilator EM 100, CPR Medical devices Inc., Toronto, Canada) por 2 minutos; Las metas del estudio se midieron con 2 neumotacómetros. La comparación bolsa autoinflable versus el resucitador mostró volúmenes corrientes promedio comparables ± SD (945 ± 104 vs. 921 ± 250 ml), flujo inspiratorio máximo (111 ± 27 vs. 45 ± 21 l/min) y presión inspiratoria máxima (1.2 ± 0.47 vs. 78 ± 0.07 kPa) significativamente mayores ($P < 0.05$), pero con tiempos inspiratorios significativamente mas cortos (1.1 ± 0.29 vs.1.6 ± 0.35 s.). Los volúmenes corrientes pulmonares fueron comparables (337 ± 120 vs. 309 ± 61 ml), pero los volúmenes corrientes del estómago (200 ± 95 vs 140 ± 51) fueron significativamente mayores con la bolsa autoinflable (P < 0.05). En conclusión, la ventilación simulada de un paciente en paro cardíaco no intubado, usando un resucitador resulta en un flujo inspiratorio máximo disminuido, y por lo tanto, en presiones de vía aérea máxima disminuidas, cuando se compara con bolsa manual autoinflable. El flujo ventilatorio limitado usando el resucitador disminuyó la insuflación gástrica, aunque los volúmenes corrientes pulmonares fueron comparables entre ambos grupos.

Palabras clave: Mascara bolsa con válvula; Reanimación cardiopulmonarr; Soporte vital básico; Insuflación gástrica; Tasa de flujo inspiratorio; Presión máxima de vía aérea

1. Introduction

When ventilating an unintubated patient, the distribution of gas between lungs and stomach depends on the patient's lower oesophageal sphincter pressure (LESP) [1], respiratory mechanics such as respiratory system compliance [2] and degree of airway obstruction [3]. Moreover, the technique of the rescuer performing basic life support (BLS) may influence inspiratory flow rate, peak airway pressure, and tidal volume [4]. Stomach inflation during BLS is a complex problem that may cause regurgitation [5], aspiration [6], pneumonia, and possibly, death [7]. Stomach inflation may also elevate intragastric pressure [8], push up the diaphragm, restrict lung movements, and thereby decrease the respiratory system compliance [9]. A decreased respiratory system compliance may force even more gas into the stomach, thereby inducing a respiratory vicious cycle with each tidal volume of increasing stomach inflation, and decreasing lung ventilation [10].

In order to prevent stomach inflation, managing peak airway pressure is therefore of fundamental importance during BLS ventilation of unintubated patients in respiratory and/or cardiac arrest. When experienced



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healthcare professionals perform bag-valve-mask ventilation, it was observed that respiratory rates were ~40 instead of ~15/min [11], and inspiratory times ~0.5 instead of ~1.5 s [12], indicating that emergency ventilation is a more complex psychomotor manoeuvre than previously thought. We have previously shown that one strategy of decreasing peak airway pressure during bag-valve-mask ventilation is simply to decrease tidal volume from 1000 to 500 ml [13]; limitation of inspiratory flow rate may be another, possibly even more effective approach. If the inspiratory flow rate is fixed, BLS ventilation may have a built-in safety margin, and ventilation quality may improve, especially when used by less experienced rescuers. Based on this concept, a flow-limited resuscitator (Oxylator EM 100, CPR Medical Devices Inc., Toronto, Canada) has been developed. (Fig. 1). Accordingly, the purpose of the present study was to assess the effects of a self inflating bag compared to this resuscitator with fixed inspiratory flow rates on respiratory variables, tidal lung and stomach volumes in a simulated unintubated cardiac arrest patient. Our hypothesis was that there would be no difference in study endpoints between groups.

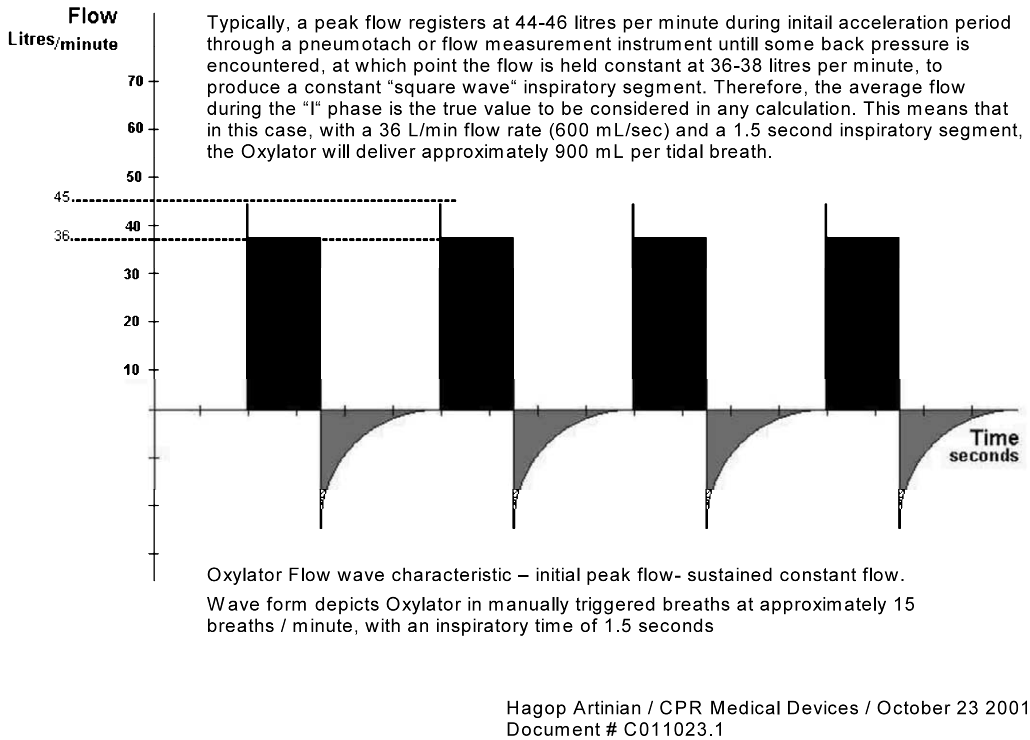
Table 1
Study end points and respiratory parameters during mask-ventilation applied with an adult self-inflating bag, and a resuscitator with limited flow

Variable	Adult bag	Resuscitator	*P*
Mask tidal volume (ml)	945±104	921±250	NS
Peak inspiratory flow (l/min)	111±27	45±21	<0.05
Peak airway pressure (kPa)	1.2±0.47	0.78±0.07	<0.05
Inspiratory time (s)	1.1±0.29	1.6±0.35	<0.05
Stomach inflation (ml)	200±95	140±51	<0.05
Lung tidal volume (ml)	337±120	309±61	NS

Results are given as mean±SD; NS, not significant.

2. Materials and methods

The experimental protocol of this study was approved by the institutional review board of the study institution. Twenty critical care unit registered nurses certified in BLS volunteered as participants for the study. The



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participants were instructed to treat an experimental model as an adult cardiac arrest patient, and ventilate the manikin via a facemask with an adult self-inflating bag (maximal volume, 1.5 l) or with the resuscitator until the chest clearly rose.

In the experimental model simulating an unintubated cardiac arrest patient, the upper airway was provided by a standard Cardiopulmonary resuscitation (CPR) manikin (Airway Management Trainer, Laerdal, Armonk, NY), with the head fixed in a hyper-extended position. After the test lung (LS 800, Draeger, Lübeck, Germany) was connected to the tracheal outlet of the manikin head, lung compliance was adjusted to 50 ml/0.098 kPa (50 ml/cmH_2O), and airway resistance to 0.39 kPa/l/s (4 cmH_2O/l/s) to simulate cardiac arrest conditions. A flow sensor from a respiratory monitor (AS 3, Compact, Datex Ohmeda, Helsinki, Finland) was inserted into the simulated trachea to measure lung ventilation. Another flow sensor (Ventcheck Model 101, Novametrix, Wallingford, CT) was placed between either the self-inflatable bag or the resuscitator (Oxylator EM 100, CPR Medical Devices Inc., Toronto) (Fig. 1), and the facemask to measure respiratory variables. The resuscitator weights $\sim$500 g, and needs to be connected to a compressed oxygen or room air source. This concept of the device is somewhat similar to a new self-inflating bag (Smart-Bag, O-two systems, Toronto, Canada) with a valve limiting peak airway pressure. The oesophagus was simulated with a 20 cm section of surgical drain (Penrose, $\frac{3}{4}$ inch internal diameter, Davol, Cranston, RI), which was connected with the oesophageal outlet of the manikin. The distal end of the oesophageal outlet of the manikin's head was further attached to a water column controlled PEEP valve (Emerson, Cambridge, MA). To simulate the LESP at cardiac arrest conditions, the PEEP valve was adjusted to 0.49 kPa (5 cmH_2O). A second outlet from the water column controlled valve was connected to a volumeter (Draeger) with a one-way valve to measure and record stomach volumes.

The volunteers were allowed to familiarise themselves with the equipment until they were comfortable with its use. To avoid a biased performance, specific tidal volumes or peak flow rates to be applied were not defined to the volunteers; however, applied tidal volume was limited by the size of the self-inflatable bags. Following the recommendations of the new international CPR guidelines, each volunteer randomly performed two 2-min attempts to ventilate the bench model with a self-inflating adult bag and with the resuscitator, which was used in the manual modes, with 12 breaths per minute, while the study endpoints were recorded. The equipment, except the manikin head, was covered with a cloth to blind the rescuers to the measurement of stomach inflation and lung ventilation. However, the rescuers were able to watch the artificial lung rise during ventilation, as in a clinical situation. The design of the model and the results of the measurements were revealed to the volunteers only after the experiment was completed.

2.1. Statistical analysis

All values are expressed as mean ± SD. Comparisons were made with the Student-t-test, and with Newmann-Keul's multiple comparison procedure. Alpha was set at 0.05 for statistical significance.

3. Results

Twenty critical care unit registered nurses (10 women, 10 men) performed bag-mask ventilation with an adult self-inflating bag, or with a resuscitator. The self-inflating bag vs. resuscitator resulted in comparable mean ± SD mask tidal volumes, significantly ($P < 0.05$) higher peak inspiratory flow rates, and peak inspiratory pressure, but significantly shorter inspiratory times. Lung tidal volumes were comparable, but stomach tidal volumes were significantly ($P < 0.05$) higher with the self-inflating bag (Table 1).

4. Discussion

In our study, we found that the self-inflatable bag vs. resuscitator resulted in comparable mean ± SD mask tidal volumes, significantly ($P < 0.05$) higher peak inspiratory flow rates and peak inspiratory pressure, but significantly shorter inspiratory times. Lung tidal volumes were comparable, but stomach tidal volumes were significantly ($P < 0.05$) higher with the self-inflating bag.

In order to examine the effects of a resuscitator providing a decreased peak flow rate (Fig. 2) during simulated BLS ventilation on the distribution of air between lungs and stomach, we used a previously established bench model of an unprotected airway [12]. The respiratory system compliance in our model was comparable with that in a patient in cardiac arrest [14]. Airway resistance was adjusted to 0.39 kPa/l/s (4 cmH_2O/l/s), which is similar to the airway resistance of healthy volunteers with no underlying lung disease [15]. Although LESP has not been measured in humans following cardiac arrest, data from an animal model showed that it deteriorated from 1.96 to 0.49 kPa (20–5 cmH_2O) during the first 5 min of untreated cardiac arrest. Thus, the design of our model with an adjustable LESP at 0.49 kPa (5 cmH_2O) may simulate closely the respiratory mechanics of a cardiac arrest patient. This bench model has the advantage that each variable of respiratory mechanics can be controlled and adjusted to investigate a certain hypothesis. In contrast, a clinical study with our hypothesis is difficult to perform due to many confounding variables that are difficult to control and to evaluate during CPR. Further, a self-inflating bag is the device that is readily available and usually used by the emergency medical service and in the hospital during the initial care of a cardiac arrest victim. Moreover, since the resuscitator is a relatively simply tool, it may reflect an alternative BLS ventilation device.

Since the respiratory mechanics of a cardiac arrest patient are relatively fixed, the best strategy to achieve a good lung tidal volume, and therefore, to prevent stomach ventilation, may be to adjust the ventilation strategy of the rescuer. In order to minimise the risk of stomach inflation, we have shown that tidal volume may be the decisive factor to decrease peak airway pressure, and therefore, to decrease the chance of stomach inflation [12]. In a subsequent clinical investigation, we revealed that smaller tidal volumes can reduce gastric inflation during induction of anaesthesia in an unprotected airway; however, a $FiO_2 > 50\%$ had to be used to ensure adequate oxygenation [16]. Accordingly, when small (500 ml) instead of large (1000 ml) tidal volumes with room air were applied in patients undergoing routine surgical procedures, the small tidal volumes were insufficient to ensure adequate oxygenation [17]. Given the fact that the airway devices used enabled the rescuers to administer a FiO_2 of $> 50\%$, there is no doubt that the applied tidal volumes were too large. This may be due to the instruction of the rescuers to ventilate the simulated patient until the chest clearly rose. Accordingly, it may be beneficial for both ventilation devices to have a certain built-in-safety feature. This could be, for example, a switch not allowing the rescuer to administer tidal volumes > 500 ml when the FiO_2 is $> 50\%$. The loss of volume when ventilating the manikin is mainly due to mask leak, which is within normal limits (400 of 900 ml, $\sim 40\%$), although the volunteers were less experienced in respiration. However, sealing the mask on the manikin's plastic head may be more difficult than on a human being; anatomical dead space and air compression may be additional factors for the loss of volume.

Use of a self-inflating bag with high ventilation rates may cause another problem. If the self-inflating bag is squeezed rapidly, the increase in peak flow rate and therefore, peak airway pressure, may increase the risk of gastric inflation [18]. In contrast, when used in the manual mode, the resuscitator requires a relatively long inspiratory time in order to make the chest rise, thus ensuring a relatively low ventilation rate per minute. Since ventilation rates in our experiment were fixed with both airway devices, differences in stomach minute ventilation were minor (self-inflating bag ~ 2400 ml; resuscitator ~ 1700 ml). However, a ventilation rate of up to ~ 40/min is achieved easily with the self-inflating bag [11], but the resuscitator will allow a maximum rate of only ~ 20/min. When extrapolating these data, stomach ventilation may be ~ 8000 ml with the self-inflating bag vs. only ~ 2800 ml with the resuscitator per minute, respectively. In this study, we demonstrated clearly that a reduced peak flow rate subsequently reduces peak airway pressure. While we decreased peak flow rate by $\sim 60\%$, stomach inflation was reduced only by $\sim 30\%$, the difference is most likely due to the longer inspiratory time. Accordingly, beneficial effects of decreased peak flow rate were covered up by the longer inspiratory time; thus, if inspiratory times would have been comparable, the beneficial effect of the resuscitator would have been even greater. In that case, however, lung tidal volumes would have decreased as well, indicating that if a rescuer decreases peak flow rate and inspiratory time, relatively small tidal volumes are likely that require a high FiO_2.

We acknowledge that the mechanics of the valve simulating the LESP in our model had no systemic compliance, as is most likely in the human stomach. The LESP in our model is a mechanical valve only, not a sphincter as in a human being with a stomach and intestines behind it. While stomach inflation in a human being may be restricted by the volume capacity of the gut, a mechanical valve allows free flow. Also, it is unknown to date whether the LESP functions as a valve, as in our experiment, or according to an all-or-nothing principle, depending on peak airway pressure. Accordingly, if the proportion of peak airway pressure that is above the LESP is simply greater with a given airway device, a model featuring a valve-type LESP would favour a device such as the resuscitator. Thus, clinical evaluations will be necessary in order to confirm our observation. The feature of the resuscitator to provide limited flow (Fig. 2) may be an advantage in preventing elevated peak airway pressure; however, this may prevent an immediate sensual feedback of ventilation efforts for the rescuer. Accordingly, these advantages and disadvantages may need to be stressed to rescuers using the device.

Some limitations of this experimental design should be noted. First, although the components of respiratory mechanics in our bench model have been carefully chosen, they cannot exactly duplicate the respiratory mechanics in a cardiac arrest patient. For example, as shown in a laboratory investigation [19], respiratory system compliance changes during chest compressions, rendering a perfect simulation of positive pressure ventilation in a nonintubated cardiac arrest patient difficult. Second, the only information about LESP changes following cardiac arrest is from an animal investigation; investigations of LESP physiology in human beings have not been done yet. However, some reduction in LESP after cardiac arrest in human beings may be assumed, as suggested by the high incidence of regurgitation and aspiration in victims of cardiac arrest, especially when the phase of ventilation with an unprotected airway is prolonged [20]. In addition, it is known that all sphincters lose tone after death.

In conclusion, simulated ventilation of an unintubated cardiac arrest patient using a resuscitator resulted in decreased peak flow rates and therefore, in decreased peak airway pressures when compared with a self-inflating bag. Limited flow ventilation using the resuscitator decreased stomach inflation, although lung tidal volumes were comparable between groups.

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