Rebreathing Bags as Pressure-limiting Devices

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Most pop-off valves can be completely closed, thereby abolishing their ability to prevent the development of excessive gas pressure in a closed breathing system. However, the elastic properties of the rebreathing bag can serve as a suitable backup system for limiting pressure. The pressure–volume curve of an elastic balloon has three phases: 1) initially, adding volume to an empty balloon causes negligible pressure increase until the nominal volume (listed capacity) is reached; 2) as more volume is added, pressure rapidly increases to a characteristic limit; 3) with the addition of still more volume, pressure slowly

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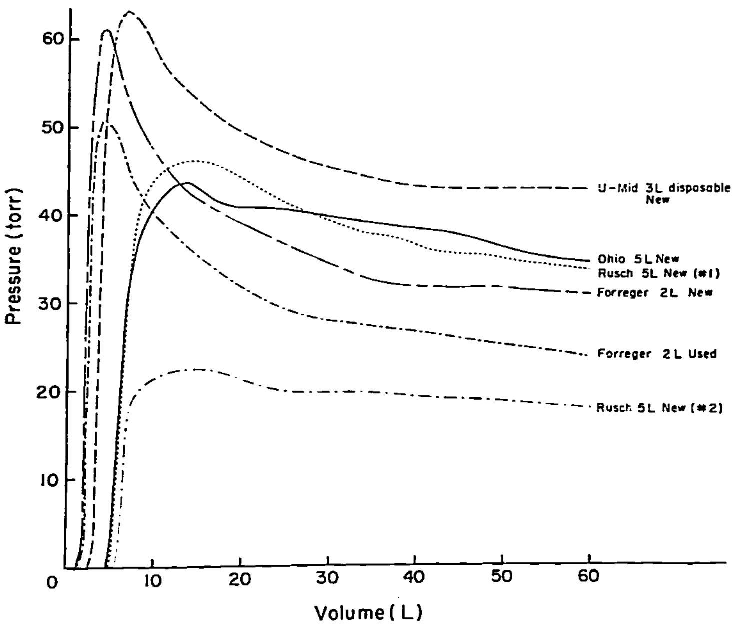

FIG. 1. These static pressure–volume curves for rebreathing bags show the typical three phases during inflation of elastic balloons: 1) zero pressure until nominal volume is reached; 2) rapid rise to a peak pressure; 3) decreasing pressure with further inflation. Anesthesia rebreathing bags vary considerably among themselves in details, however. Two new 5-liter bags had quite different peak pressures (see Rusch #1 and #2). Used bags generally have lower peaks than new (see the new and used Foregger 2-liter bags, for example). The U-Mid 3-liter bag is relatively inelastic and has a very high peak pressure.

decreases as the radius of the bag increases (according to the Laplace inverse relationship of pressure and radius) until the bag fails or the elastic limits are exceeded. The value of the characteristic peak pressure interests anesthetists, as it represents the maximum that will develop in a closed breathing system with inadvertent closure of the pop-off valve and continued gas inflow. Reports suggest that at 60 torr transthoracic pressure, air embolism and pneumothorax become significant dangers.[1] One can find rebreathing bags with peak pressures considerably above and below this value.

We studied the pressure–volume characteristics of a variety of rebreathing bags, using a super-syringe, stopcock, and anaeroid manometer to produce static pressure–volume curves. All rebreathing bags had pressure–volume curves of roughly the same shape. Typical static curves are shown in figure 1. The maximum static pressures of the rebreathing bags tested ranged from 22 torr for a used Rusch 5-liter bag to 120 torr for a new Ohio Medical Products 3-liter disposable bag; their peak pressures occurred at 15- and 5-liter volumes, respectively. Different new bags from the same manufacturer had somewhat different peak pressures. For example, peak pressures of ten new Rusch 5-liter bags ranged from 22 to 43 torr. Peak pressures tended to be lower in used bags.

All rebreathing bags showed stress relaxation, *i.e.*, when the bag volume was increased, a finite period of time (relaxation time) was necessary for elastic equilibrium to be attained. Relaxation times ranged from 1 to 5 seconds for the bags we examined. This property makes bag pressures during inflation (dynamic) slightly greater than those in the equilibrated state (static). At gas inflow rates of 6 l/min or less, the pressure is usually less than 3 torr higher than static pressure at the same volume. The difference depends mostly on the rate of volume increase, and may be 15 torr during flushing with oxygen.

The anesthetist can easily determine the peak pressure possible in his circle system by closing the pop-off valve, occluding the Y piece, opening the oxygen flush, and watching the pressure gauge. Most bags will stretch to extraordinarily large volumes (more than 100 liters) without bursting, although the outer conductive layering may flake off. The peak pressure of a new bag will decrease after several overdistentions to volumes of 10 to 20 liters without destruction of the elastic or conductive properties of the bag. Thus, if the peak pressure is considered excessive, ballooning the rebreathing bag several times to approximately 10 liters will lower it. We lowered the peak pressures of ten rebreathing bags approximately 20 torr each after eight balloonings to 10 liters and without flaking of the outer conductive layer. A low peak pressure for the unsqueezed bag does not limit the anesthetist's ability to produce higher airway pressures, as some might think, because compressing the rebreathing bag reduces its radius of curvature, and for any given elasticity, inversely increases the achievable pressure (fig. 2).

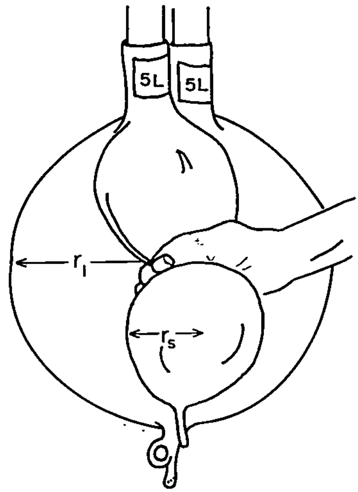

FIG. 2. Compression of the rebreathing bag may halve the radius of curvature ($r_s = \frac{1}{2} r_1$) and allow a pressure twice as high as the characteristic peak pressure of the spherically inflated bag since, from the law of Laplace, pressure is inversely proportional to radius.

The elastic characteristics of rubber can increase the safety of properly designed anesthesia equipment. Prestretching a new rebreathing bag assures that with inadvertent overinflation the pressure will not exceed 30 to 35 torr. This is similar to prestretching the cuffs of some new disposable endotracheal tubes to lower their pressures.

REFERENCE

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The Use of Mechanical Ventilation with Positive End-expiratory Pressure in the Treatment of Near-drowning

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The following case of fresh-water near-drowning with aspiration emphasizes the reversibility of the pulmonary injury and illustrates the benefit of mechanical ventilation with positive end-expiratory pressure (MV with PEEP) in treatment.

REPORT OF A CASE

A 16-year-old boy was admitted to our care five hours after near-drowning in chlorinated fresh water with aspiration. The boy's health had been good, and a chest x-ray ten months earlier had disclosed no abnormalities. Submersion was estimated to have lasted 3 minutes. Upon removal from the water, the boy had a pulse but was unconscious and required mouth-to-mouth resuscitation. When respiration returned, it was rapid and shallow, and frothy secretions and cyanosis were present.

Upon arrival in our emergency room two and a half hours later, the patient had pulmonary edema with cyanosis, tachypnea, and tachycardia, but was not hypotensive. Initial arterial blood gases, measured while oxygen was being delivered by face mask, indicated marked hypoxia and desaturation, hypercarbia, and slight acidemia (Pa_{O_2} 25 torr; sat 40 per cent; Pa_{CO_2} 46.5 torr; *p*H 7.32). An endotracheal tube was introduced and respiration was assisted with an Ambu bag during transport to the intensive care unit, where ventilation was then assisted with a volume ventilator supplying 100 per cent oxygen. A marked alveolar–arterial oxygen gradient (578 torr) persisted in spite of good mechanical ventilation, so controlled MV with PEEP at 10 cm H_2O was instituted three hours later. A rapid and dramatic improvement in the oxygen gradient (384 torr) followed the application of PEEP, and the inspired oxygen concentration had been reduced to 40 per cent one and a half hours later. Several hours later, PEEP was reduced to 5 cm H_2O and maintained there for the next 24 hours while the oxygen concentration was further reduced. Four hours after cessation of PEEP, weaning from artificial ventilation was begun with a T tube; seven hours later, the trachea was extubated. Supplemental oxygen was administered for an additional 14 hours. Chest physiotherapy was continued and assisted hyperinflation was utilized periodically until the patient's discharge on the sixth hospital day. The patient had awakened fully within six hours of admission, and no residual neurologic deficits were present. When he was discharged, his chest was clear to auscultation and x-ray.

Laboratory data of interest include serum K, which was 5.6 mEq/l on admission, at which time the blood was "4+ hemolyzed." Two hours later, serum K was 3.7 mEq/l, serum-free hemoglobin was 24.8 mg/100 ml, and serum osmolarity was 277 mosm/l. Although hemolysis and hyperkalemia were present, urinary discoloration was transient, and no arrhythmia occurred. Serum enzymes were elevated initially and reached a peak approximately 12 hours later. Serum bilirubin was also elevated, and the elevation persisted for three days (maximum 1.8 mg/100 ml). The x-rays (fig. 1) and graph (fig. 2) illustrate the severity

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