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USING THE INFLATING SYRINGE AS A SAFETY VALVE TO LIMIT LARYNGEAL MASK AIRWAY CUFF PRESSURE

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ABSTRACT. Objective. Hyperinflation of the laryngeal mask airway (LMA) cuff is thought to be the etiology underlying many of the complications associated with the use of this device. Until now, there has not been a clinically acceptable method (besides direct measurement) to assure that the cuff pressure is maintained less than the recommended maximum value of 44 mm Hg (60 cm H_2O). **Methods.** We inflated sizes #2 and #5 LMAs with air to 40, 60, or 120 mm Hg starting pressures, using 30- and 60-ml BD™ and B Braun™ syringes; we then allowed the syringe plungers to recoil to equilibrium before removing the syringe from the LMA inflation port. Residual LMA cuff pressures following complete passive recoil were measured and recorded. **Results.** A number of combinations of syringes (30 and 60 ml) and starting pressures (40, 60, 120 mm Hg) resulted in safe residual (#2 and #5 LMA) cuff pressures of <44 mm Hg. **Conclusion.** When using specific combinations of syringes, LMA sizes and inflation pressures, these data demonstrate an efficient, practical and easy method to achieve an initial equilibrium recoil LMA cuff pressure that is less than, or very near to, the recommended upper safe limit of 44 mm Hg.

KEY WORDS. laryngeal mask airway, laryngeal masks, airway management, postoperative complications, cuff pressure.

INTRODUCTION

The laryngeal mask airway (LMA) is a popular tool for airway management during general anesthesia. As with any airway device, potential complications including minor events such as sore throat (incidence of 6–34%) [1–3] to more serious sequelae such as arytenoid dislocation [4] and nerve damage may occur [5–7]. A recurring theme of these complications revolves around the role that hyperinflation of the LMA cuff may play, because an excessively inflated, overly pressurized cuff may cause pressure injury to the perfusion-dependent, highly specialized soft tissue architecture that comprises the larynx and surrounding pharyngeal tissue.

The manufacturers of LMA devices advise limiting cuff inflation to a specific volume and pressure [8].[1] Additionally, Brain has long recommended that the cuff pressure be measured to make certain that a pressure of 44 mm Hg is not exceeded [9, 10]. Notwithstanding these manufacturer/inventor guidelines, few practitioners

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[1]LMA™ Airway Instruction Manual. San Diego, LMA North America Inc., 2005.

actually heed this advice [11]. For instance, Haldar and Immanuel [12] noted during a prospective audit that 76% (43/56) of LMA cuff pressures were greater than 44 mm Hg. Even more worrisome, almost half (48%) of the intra-cuff pressures were greater than 88 mm Hg. This frequent occurrence of high LMA cuff inflation pressures was confirmed by Lenior, [13] who in a series of 63 patients noted LMA mean cuff pressures of 132 mm Hg at the start of the anesthetic, and 153 mm Hg at the end of the case. Seet [3] also noted LMA cuff pressures averaging 107 mm Hg. Thus, LMA cuff pressures commonly (and unknowingly) accepted in anesthetic care frequently and significantly exceed the manufacturers' recommendations; systematic improvement in the care of patients whose airway is managed with an LMA is therefore a worthwhile goal. Seet and colleagues [3] recently reported a reduction in the rate of postoperative pharyngolaryngeal complications from 46% with routine LMA cuff care (mean cuff pressure 114 ± 57 mm Hg) to 13% incidence when the LMA cuff pressure was limited to <44 mm Hg. These findings inspired us to design and validate an efficient and practical method of maintaining the LMA cuff pressure under (or at least much nearer to) this recommended maximum inflation pressure.

In the operating room, we observed that following inflation of an LMA with the pre-packaged accompanying B. Braun™ (BB) syringe, if the syringe remained engaged to the spring-loaded pilot valve leading to the cuff, the syringe plunger commonly rebounded, resulting in a lesser degree of LMA cuff inflation. We hypothesized the intra-cuff pressure of the LMA forced the syringe plunger to rebound and, more importantly, that the residual LMA cuff pressure would be closer to, or even within, the recommended "safe zone" of pressure (i.e., ≤ 44 mm Hg). Hence the syringe might be used as a readily available, rapid, and effective pressure limiting "safety valve."

METHODS AND MATERIALS

We attached a 30- or 60-ml B. Braun™ (B. Braun Medical Inc., Bethlehem, PA) or BD™ (Becton, Dickinson and Co., Franklin Lakes, NJ) Luer lock syringe to a size #2 or #5 Ambu® LMA (Ambu Inc., Glen Burnie, MD) and measured the residual pressure of the syringe resulting from various initial starting inflating pressures. A new syringe was used for each trial. Each syringe was connected in parallel to both a three-way stopcock and a zeroed TruWave® disposable pressure transducer (Edwards Lifesciences, Irvine, CA). The stopcock was open to all three ports and the LMA inflation valve. The pressure transducer thereby measured the pressure throughout the system, including that in the LMA cuff and the syringe (Figure 1). The 30- and 60-ml syringes (n = 20 for each brand and size) were attached to the stopcock, after which each syringe and LMA cuff was initially pressurized to 40, 60 or 120 mm Hg for 10 s to prove integrity of the system and then allowed to recoil passively and completely. The resulting pressure was recorded as the recoil pressure of the particular syringe and starting pressure.

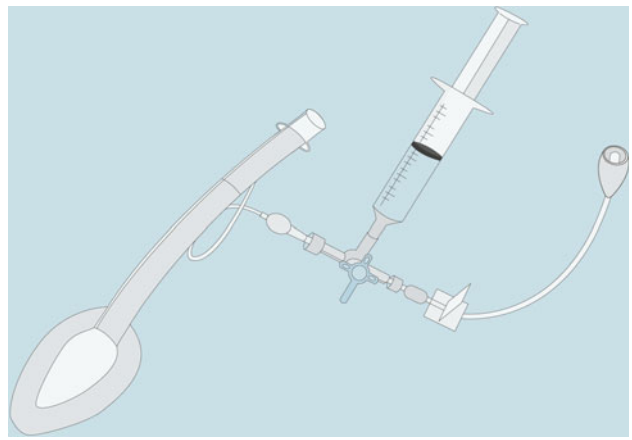

Fig. 1. The experimental set-up. The cuff of the laryngeal mask airway (LMA), the syringe, and the pressure transducer connected to a three-way stopcock.

Statistical methods

Summary data are reported as mean ± standard deviation (SD). Comparisons between groups of continuous data were conducted for each syringe size (30 or 60 ml) or type (BB or BD) using two-way repeated measures analysis of variance (factor 1: syringe size or type; factor 2: starting cuff pressures of 40, 60, or 120 mm Hg) with post-hoc Tukey method pairwise testing to correct for multiple comparisons, when appropriate (SigmaPlot 11.2, Systat Software, Inc., Chicago, IL, USA). Nominal data (above or below the maximal recommended pressure) were compared using Chi Square with Yates correction. $P < 0.05$ was considered statistically significant.

RESULTS

As shown in Figure 2, the 60 mL BB syringe caused an overall greater residual cuff pressure compared to the 30 ml BB syringe ($P < 0.001$) in size #2 LMA devices. Comparing the two syringe sizes, no differences in residual pressures were noted for starting pressures of 40 mm Hg ($P = 0.73$, n = 20/syringe size) or 60 mm Hg ($P = 0.06$,

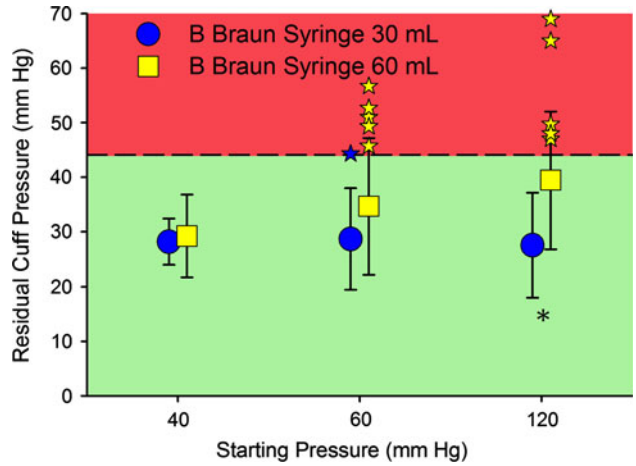

*Fig. 2. The resulting laryngeal mask airway (LMA) cuff residual pressure following inflation of size #2 LMA to a noted starting pressure (40, 60, or 120 mm Hg) with a 30- or 60-ml B. Braun (BB) syringe. Data shown are mean ± SD for 20 observations. The horizontal, dashed line denotes the maximal recommended residual pressure (44 mm Hg) following LMA placement. The stars represent individual observations greater than 44 mm Hg (60 cm H_20). *$P < 0.05$ for 30 ml syringe compared to 60 ml syringe for a given starting pressure.*

n = 20/syringe size), but inflation to 120 mm Hg with a 60 ml syringe did cause a greater residual pressure compared to that following inflation with a 30 mL syringe ($P < 0.001$, n = 20/syringe size). Additionally, the 60 ml syringe size resulted in significantly more frequent (10 of 60 observations) LMA residual cuff pressures that were greater than the maximal recommended pressure of 44 mm Hg compared to the 30 mL syringe (1 of 60 observations, $P = 0.01$). Irrespective of which syringe was used, increasing the starting pressures from 40 to 60 and 120 mm Hg tended to elevate residual cuff pressures, but these differences did not achieve statistical significance ($P = 0.09$).

Next, we compared the residual cuff pressures only in LMA size #5 following inflation with a 30-ml BD or BB syringe as shown in Figure 3, panel A. Both the starting pressure ($P < 0.001$) and the type of syringe ($P < 0.001$) affected the residual cuff pressure although no interaction was observed between these two factors (P = 0.18). That is, the 40 mm Hg starting pressure (n = 20/syringe type) caused a significantly lesser residual cuff pressure than did the 60 mm Hg ($P = 0.01$, n = 20/syringe type) or 120 mm Hg ($P < 0.001$, n = 20/syringe type) starting pressures. The BD syringes resulted in higher residual cuff pressures than did the BB syringes after starting pressures of 60 mm Hg ($P < 0.001$) and 120 mm Hg ($P < 0.001$), but the difference was not significant for the 40 mm Hg starting pressure ($P = 0.10$). Although (as expected) no cases of residual cuff pressures >44 mm Hg were noted following starting pressures of 40 mm Hg, we did observe

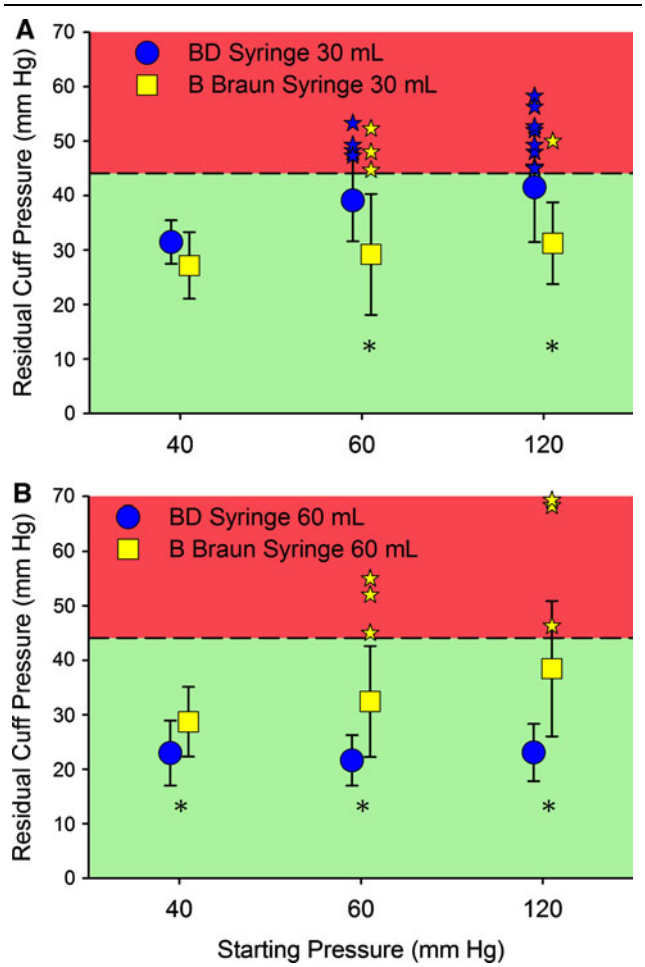

*Fig. 3. The resulting laryngeal mask airway (LMA) cuff residual pressure following inflation of size #5 LMA to a noted starting pressure (40, 60, or 120 mm Hg) with either a 30-ml (A) or 60-ml (B) Becton–Dickinson & Co. (BD) or B. Braun (BB) syringe. Data shown are mean ± SD for 20 observations. The horizontal, dashed line denotes the maximal recommended residual pressure (44 mm Hg) following LMA placement. The stars represent individual observations greater than 44 mm Hg (60 cm H_20). *$P < 0.05$ for BD syringe compared to BB syringe for a given starting pressure.*

several instances of residual cuff pressures exceeding the recommended limits following inflation with 60 and 120 mm Hg starting pressure. In addition, the nature of distribution of these cases indicated that the BD syringes resulted in more frequent residual cuff pressures >44 mm Hg than did the BB syringes ($P = 0.04$).

Finally, we studied the residual cuff pressures using the 60 ml BB or BD syringes as shown in Figure 3, panel B. Both the starting pressure ($P = 0.02$) and type of syringe ($P < 0.001$) affected the residual cuff pressure. In addition, a significant interaction existed between these two factors ($P = 0.004$). For the BD syringes, the starting pressure did not appear to affect the residual cuff pressure,

whereas the BB syringe resulted in a markedly greater residual cuff pressure following starting pressures of 120 mm Hg compared to 40 mm Hg inflation ($P < 0.001$, n = 20/syringe type), but not compared to 60 mm Hg inflation pressure ($P = 0.05$, n = 20/syringe type). In addition, the 40 and 60 mm Hg starting pressures tended to cause different residual pressures for the BB syringes, but these differences did not achieve statistical significance ($P = 0.31$). For all pressures, the BB syringes produced significantly greater residual cuff pressures than did the BD syringes. Comparing the distribution of residual cuff pressures >44 mm Hg, the BB 60 ml syringes caused a greater proportion of residual cuff pressures exceeding the recommended maximum pressure than did the BD 60 mL syringes ($P = 0.04$).

From Table 1, which is a summary of all the experiments, it can be calculated that two standard deviations of residual pressure above the mean pressure is approximately 44 mmHg and should provide a range of safe inflation pressures in about 97.7% of patients using either BB or BD syringes with a variety of initial (pre-recoil) inflation pressures.

DISCUSSION

In this report, we have detailed a novel application and use of two sizes and brands of syringes used for LMA cuff inflation as a means to limit the residual LMA cuff pressure in the operating room, and be more consistent with recommendations designed to minimize laryngopharyngeal injuries from LMA cuff overinflation. Brimacombe and Brain [14] recommended a maximal LMA cuff pressure of 44 mm Hg, although the method for arriving at this value is not completely clear.

The recent report by Seet and colleagues [3] showing a very high incidence (45.6%) of sore throat with routine LMA cuff inflation strategies compared to the much lower incidence (13.4%) when the cuff pressure is kept below 44 mm Hg reinforced the need to devise an easy way to reasonably ensure that LMA cuff inflation pressures are in a safe range.

The recommended method to assure that residual LMA cuff pressure is in an acceptable range is to measure the pressure using manometry; however, this task adds extra expense, time, and leads to additional anesthetic record

Table 1. The summation of the residual cuff pressures for all experiments shown as the mean and standard deviations (one, two, three, and four) in mm Hg

LMA size	Syringe type and size (ml)	Starting pressure (mm Hg)		μ	$\mu + 1\sigma$	$\mu + 2\sigma$	$\mu + 3\sigma$	$\mu + 4\sigma$
			<60 cm H_2O		**84.1%**	**97.7%**	**99.9%**	**100.0%**
			>60 cm H_2O		15.9%	2.3%	0.1%	0.0%
5	BD 60	60		**22**	**26**	**31**	**36**	**40**
5	BD 60	40		**23**	**29**	**35**	**41**	47
5	BD 60	120		**23**	**28**	**34**	**39**	44
2	BB 30	40		**28**	**32**	**37**	**41**	45
5	BB 30	40		**27**	**33**	**39**	46	52
5	BB 60	40		**29**	**35**	**42**	48	54
5	BD 30	40		**31**	**35**	**39**	43	47
2	BB 30	120		**28**	**37**	47	56	66
2	BB 30	60		**29**	**38**	47	56	66
5	BB 30	60		**29**	**40**	51	63	74
2	BB 60	40		**29**	**37**	44	52	59
5	BB 30	120		**31**	**39**	46	54	61
5	BB 60	60		**32**	**43**	53	63	73
2	BB 60	60		**35**	47	60	72	85
5	BB 60	120		**38**	51	63	76	88
5	BD 30	60		**39**	47	54	62	69
2	BB 60	120		**39**	52	65	77	90
5	BD 30	120		**42**	52	62	72	82

The bold area of the table is the resulting mean plus standard deviation (either 1, 2, 3, or 4 SD) that fell below the recommended level of cuff inflation pressure of 60 cm H_2O (44 mm Hg). Legend: *BB* B. Braun syringe, *BD* Becton–Dickinson syringe.

documentation. Although most anesthesiologists do not routinely measure LMA pressures, [11] practitioners in at least one institution attempt to measure LMA pressure with a handheld manometer during every case (Scott R. Springman, MD, personal communication). An alternative solution would be the installation of a Lanz valve, which has been show limit pressure in endotracheal tube cuffs [15].

Our data suggest that the residual pressure in a LMA cuff can be limited by employing a 30-or 60-ml BB or BD syringe in a simple maneuver at the time of LMA insertion. That is, using the results presented herein, a clinician may be better able to inflate an LMA cuff to provide a seal with a net LMA cuff inflation pressure that is closer to or below the target of 44 mm Hg without directly measuring the residual pressure with a manometer. More specifically, practitioners can use the rebound of the syringe plunger to limit the LMA cuff residual pressure.

One of the limitations of the current study is that the LMAs were tested in the laboratory, and it is possible, though unlikely, that the resulting pressures would be different if tested in patients. However, if nitrous oxide is used and the LMA cuff is made with silicon (e.g., the Classic LMA), it is likely that the LMA cuff pressure would rise during the course of the anesthetic [16]. There may also be a small rise in pressure when air in the cuff rises from room to body temperature. A simple manipulation of the ideal gas equation (PV = nRT), reveals that a rise in cuff temperature from 23 to 37°C would increase the cuff pressure from 44 mm Hg to 46 mm Hg (see Appendix for calculations). Additionally, there are other marketed syringes that might also result in safe residual pressures, but we would recommend that each institution test syringes to assure the resulting cuff pressures fall within the safe zone if passive inflating syringe recoil is used to limit LMA cuff inflation pressures. Since the exact pressure will not be known following each inflation, the clinicians should test their system with a manometer when initiating this practice. Because this is an in vitro study, the resulting efficacy of this technique has not been proven in a clinical situation. A follow-up study is currently underway to test the effectiveness of this method on reducing the incidence of sore throat following LMA use. Finally, the syringes used in our in vitro experiment were previously unused and dry. It is likely that the use of wet syringes (i.e., that were previously used for drug administration) would change the friction characteristics of the plunger and barrel and result in different residual cuff pressures.

In conclusion, our data and suggested technique provide a consistent, efficient and reproducible method of preventing overinflation of the LMA cuff. Although a number of combinations of syringes and inflation pressures yielded a safe result, the BD 60 mL syringe at any of our tested inflation pressures was the most favorable combination. The intended cuff pressure is less likely to exceed 44 mm Hg (60 cm H_2O), and the LMA cuff will be unlikely to deflate excessively thus decreasing the effective seal. In cases of inadequate seal or any other concerns about the actual LMA cuff pressure, direct pressure measurement (manometry) remains the preferred technique.

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APPENDIX

For an ideal gas, we know that PV = nRT,

Where: P = pressure, V = volume, n = moles of the gas, R = gas constant, and T = temperature.

1. First, we calculate moles of air in the LMA cuff at room temp of 23°C:

   P = 44 mm Hg (60 cm H_2O)

   V = 30 ml (the volume recommended for the cuff of an #5 LMA)

   R = 8.314472 J K^{-1} mol^{-1}

   n = moles gas in the cuff

   T = 23°C

   Using an online calculator (http://www.chemicool.com/idealgas.html):

   The moles of gas in the cuff = $7.1475e^{-05}$

2. Now, calculate pressure (assuming volume remains constant) at 37°C, where V = 30 ml, R = 8.314472 J K^{-1} mol^{-1}, n = $7.1475e^{-05}$ mol of gas, and T = 37°C:

   The pressure at 37°C = 46.08 mm Hg

   Therefore, as temperature increases from 23 to 37°C, the pressure in the cuff increases by 2 mm Hg (44–46 mm Hg).

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