

Appropriate deflation and inflation of the LMA for adults

An ex-vivo study

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Background

It is widely recognised that excess intra-cuff pressure (CP, henceforce) in Laryngeal Mask Airways (LMA) causes post-op complications such as sore throat, hypoglossal nerve paralysis, 12th nerve paralysis, vocal cord paralysis, and /or lingual artery compression [1-11]. By maintaining appropriate CP during the procedure, these complications can be significantly avoided. For example, sore throat, which is the most common post-op complaint by patients, was reported by 40.8% where CP was at maximum or more. Whilst when the CP was maintained at less than recommended maximum CP, reports of sore throat was on 15.4%[11]. Literature reported that even after optimal CP is observed at insertion of the LMA, its CP will not remain the same depending on the length of the procedure, type of the gas used for inflation, or the anaesthetic gas. When room air is used as the inflating gas, after 30minutes, an increase of 20% of the original inflating gas pressure was measured [13]. Nitrous oxide and carbon dioxide will rapidly diffuse into the cuff, thus CP will increase even more [17]. Therefore awareness regarding value of proper LMA CP control is extremely important. Continuous monitoring of CP during the procedure using a pressure gauge is crucial. In particular, CP at insertion plays an important role in preventing hyper-CP.

In reality, many anaesthetists and their assistants do not use cuff pressure gauge as their routine practice. Anaesthetists tend to observe their own preference in preparing LMAs regardless of manufacturer's instruction. For instance, some anaesthetists prefer to 'fully deflate', while some others prefer 'not to deflate' or 'fully deflate and add 10mL of air'. Anaesthetic assistants prepare LMAs by deflating air as much as they please and after the insertion, they inflate air until cuff does not show air leak. Anaesthetic assistants normally use 20~60mL syringes to perform both deflation and inflation regardless of the LMA size. In addition, many anaesthetists and their assistants do not routinely check CP during the procedure. Due to the absence of monitoring CP using a CP gauge, hyper pressure in LMA may have been occurring intra-operatively without being noticed [10, 15]. It will be possible that CP has already exceeded optimal pressure even before being inserted and continue to increase during the procedure. In consequence, patients face higher risk of post-op complications. Assisting LMA insertion may seem to be a relatively simple task for anaesthetic assistants, however, blindly performing deflation and inflation on the LMA may be forcing the patient to bear unpleasant experience after the procedure.

Above all, there seem to be no established methods available regarding LMA preparation and inflation. Textbooks and practice manuals provide descriptive instructions on LMA insertion techniques. Some of these are summarised in Table 1. Deflation and inflation are commonly instructed, however, descriptions of these are rather subjective. The interpretation of 'correct cuff deflation', for example, will be performed significantly differently depending on the individual. Similarly, 'desired inflation volume' will also vary from person to person.

Table 1: Descriptions and instructions related to LMA insertion seen in published resources

Resource	Author	Description/Instruction	
		Deflation	Inflation
· Principles of Airway Management, 3 rd Edn [22]	Finucane BT, Santora AH	Completely deflate	Inflate with enough air to obtain seal at 18-20cmH ₂ O
· Clinical Anaesthesia Procedures of the Massachusetts General Hospital, 7 th Edn [23]	Dunn PF, <i>et.al</i>	Ensure correct cuff deflation	Inflate cuff up to 20/30/40mL
· Clinical Practice Procedures: Airway management/Laryngeal mask airway insertion[24]	Queensland Government	Deflate until the distal end of the cuff is curled anteriorly	Inflate to the desired volume
· Clinical Anaesthesiology, 4 th Edn [25]	Morgan. GE, <i>et.al</i>	Deflate tightly with the rim facing away from the mask aperture, no folds near the tip, wrinkle-free	Inflate with the correct amount of air
· Advanced Life Support Level 2, 3 rd Edn. [26]	Gale M, <i>et.al</i>	Deflate fully	Inflate cuff with air (up to 40mL for size 5 LMA and up to 30mL for size 4 LMA)

Manufacturers also provide ‘how to use’ instructions on each package and/or the airway tube of the LMA. Some of these are shown in Table 2. These instructions are rather brief, not giving concrete guidance. Maximum recommended inflation air volume and maximum CP are indicated over all of these LMAs, however, no other concrete instructions are commonly seen. They do not specify how much volume to be deflated or how much air to be inflated in order to maintain recommended CP. Even though maximum recommended volumes are commonly indicated, related studies report that these volumes would result in reaching far over 60cmH₂O, or reach 60cmH₂O with much less volume of air [8,10,13,19,21]. Among these brands of LMAs, *LarySeal* and *PRO-Breathe*, indicate further instructions, however, these are still not generally applicable for all LMAs. For example, it is not feasible for *LarySeal* to obtain optimal CP without using its original syringe. In case of *PRO-Breathe*, there is a large gap between recommended CP (i.e., 18-20cmH₂O) and maximum CP (i.e., 60cmH₂O). In addition, there is not enough evidence to confirm that sufficient air seal can be obtained by setting CP at 18-20cmH₂O. Amongst related studies, the minimum CP to maintain a good seal during procedure vary. Morris and Marjot found that CP at 28.6cmH₂O (22mmHg) during the procedure provides a good seal [20]. On the other hand, Keller reported that CP between 19.5 and 21.3cmH₂O provide minimum seal [12]. In any case, desired CP cannot be achieved and/or confirmed without the use of proper CP gauge.

Table 2: Manufacturers’ instructions

Brand	Manufacturer	Instruction regarding:			
		Deflation volume	Inflation volume	Maximum CP	Other
L.M.A	Teleflex, Ireland	No indication	Max volume indicated depending on size ‘Do not exceed max volume’	<60cmH ₂ O	
Solus	Intersurgical, UK	A figure indicates to ‘Flat’ or ‘Deflate’ No volume indicated	Max volume indicated depending on size ‘Do not exceed max volume’	<60cmH ₂ O	
LarySeal	Flexcare, UK	As shown on its cuff inflator	1/3 of maximum air	<60cmH ₂ O	
Ambu	Ambu, USA	A figure indicates to ‘Flat’ or ‘Deflate’ No volume indicated	Max volume indicated depending on size ‘Do not exceed max volume’	<60cmH ₂ O	
PRO-Breathe	Proact Medical, China	‘Deflate’ No volume indicated	Max volume indicated depending on size ‘Do not exceed max volume’	<60cmH ₂ O	Obtain an airway at 18-20cmH ₂ O

Considering the relatively expensive cost of CP gauze, providing proper CP gauze to all theatres for anaesthetists and anaesthetic assistants to use may not be practicable. Realistically, the use of syringes is the most practical and cost-effective method to control CP [15] as long as such method can provide stable, safe and easy practice in LMA CP control. Given that anaesthetists and anaesthetic assistant have not always been following uniformed practice, the CP gauge is not always available, and there are not any established guidelines, this study aims at suggesting a simple and practical guide for anaesthetic assistants by investigating:

- CP and air volume relationship; and
- Practical deflation and inflation air volume to prevent over-inflation.

Methods

Phase 1: CP-Air volume relationship and formulation of a hypothesis regarding maximum air volume

BRO-Breathe standard silicone LMA (Well Load Medical Co., LTD, China) size 3, 4 and 5 were used for the entire investigation. The numbers of LMA measured were 21, 27, and 18 respectively. A three-way tap was connected to the LMA and the CP gauge (*VBM Cuff Manometer*, VBM Medizintechnik GmbH, Germany) was connected to the second port of the tap. In order to eliminate possible residual pressure in the mask, the three-way tap was opened to the air so that the CP is set at atmospheric pressure. A 10mL BD syringe¹ was connected to the third port and air was injected. The inflated air volume was read at every 10cmH₂O increase until CP reached 120cmH₂O.

¹ Initially a 20mL syringe was used, however, it did not have at 0.1mL gradation, thus changed to 10mL for accurate measurement.

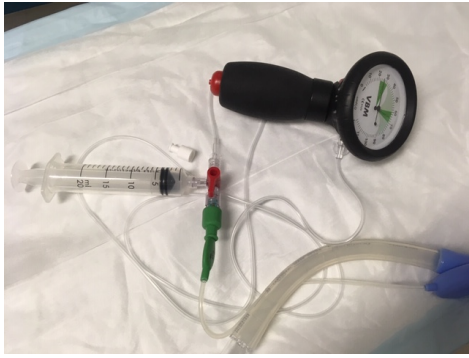


Figure 1: Connection of LMA, CP Gauge and syringe

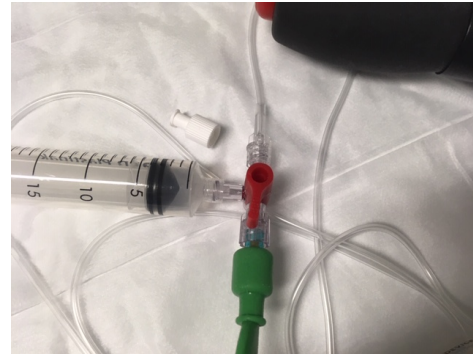


Figure 2: Connection around three-way tap

In order to form a hypothesis, mean air volume, which made CP to 60cmH₂O was calculated. Mean volume will be described as 'Potential Maximum Air Volume (Pot-MAV)' thereafter. Hypothetically, deflated air volume plus Pot-MAV should be <60cmH₂O.

Phase 2: Testing the hypothesis, observation of deflating volume, and determination of Practical Maximum Air Volume (Prac-MAV)

LMA, CP gauge and a BD 30mL syringe were connected to a three-way tap, as they were set during Phase 1. As manufacturer's instructions do not indicate to what extent the LMA should be deflated, LMA was deflated until its CP reached 20cmH₂O below zero so that all measurements would start on the observable same platform. The volume deflated was noted. During deflation process, the shape of the mask was closely observed in the view of whether the mask became flat before its CP reached 20cmH₂O below zero. Then, the deflated volume plus Pot-MAV was inflated and CP was recorded. Should the hypothesis not be rejected, observed CPs should not exceed the maximum CP of 60cmH₂O, thus Pos-MAV equals to Prac-MAV.

Should the hypothesis be rejected, appropriate prac-MAV would be sought. For this purpose, LMA was inflated with deflated air volume plus much smaller volume than Pot-MAV, 2mL of air instead of Pot-MAV, and CP measured. This measurement is to be repeated by replacing Pot-MAV with 2.5, 3.0, 3.5, 4.0, and 4.5mL of air. Amongst these 6 air volume settings, the one which made CP readings >60cmH₂O and close to 60cmH₂O could be selected on each size of LMA as Prac-MAV.

Results

Phase 1:

Table 3 shows mean cuff volumes needed to reach a LMA to one of the set pressures. Required air volume to obtain the set CP vary amongst the same size of LMAs, however, CP exceeds recommended maximum CP (i.e., 60cmH₂O) before the air volume comes to manufacturer's recommended maximum volume. In all measurements across all sizes of LMAs, CP reached 60cmH₂O with less than 6mL of air.

Table 3: Air volume to reach set cuff pressure

Cuff Pressure (cmH ₂ O)	Air volume (mL)		
	Size 3 (Range)	Size 4 (Range)	Size 5 (Range)
20	1.21 (0.9 - 1.6)	1.45 (1.1 - 2.1)	1.99 (1.6 - 2.5)
30	1.81 (1.4 - 2.3)	2.06 (1.7 - 2.7)	2.73 (2.4 - 3.5)
40	2.38 (2.0 - 2.8)	2.65 (2.2 - 3.2)	3.59 (3.2 - 4.3)
50	2.97 (2.4 - 3.8)	3.35 (2.9 - 4.0)	4.32 (4.0 - 5.0)
60	3.55 (3.0 - 4.2)	3.95 (3.2 - 4.5)	5.17 (4.8 - 5.9)
70	4.11 (3.6 - 4.7)	4.57 (3.8 - 5.0)	6.20 (5.6 - 7.5)
80	4.47 (4.1 - 5.5)	5.18 (4.2 - 6.0)	7.00 (6.4 - 8.5)
90	5.32 (4.7 - 6.0)	5.79 (4.8 - 7.0)	7.84 (7.0 - 9.5)
100	5.86 (5.2 - 6.5)	6.34 (5.2 - 7.5)	8.69 (8.0 - 10.2)
110	6.43 (5.9 - 7.0)	7.02 (5.8 - 8.5)	9.29 (8.6 - 11.0)
120	7.07 (6.5 - 8.0)	7.56 (6.2 - 9.0)	10.21 (9.2 - 12.1)

Figure 3 illustrates CP-Air volume relationship on 3 sizes of LMAs. CP increases steadily and rapidly even addition of very small volume of air.

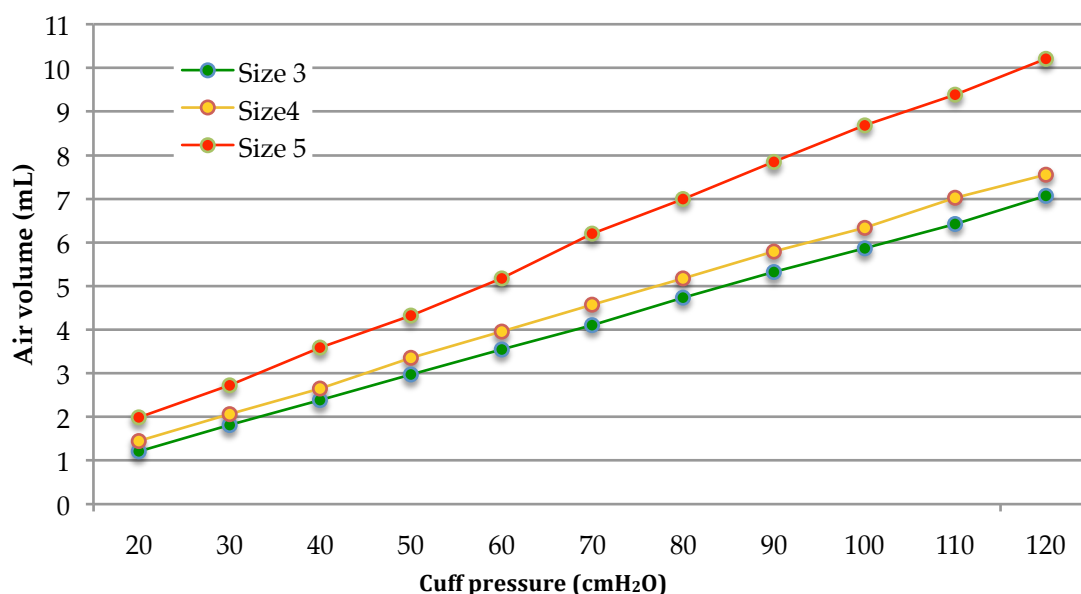


Figure 3: CP-Air volume relationship

Values are mean, air inflated from atmosphere pressure (i.e., LMAs are not deflated)

A hypothesis was formed as: If a LMA is inflated with deflated volume plus Pot-MAV, its CP will not exceed 60cmH₂O, thus Pot-MAV are to be used as Prac-MAV. (i.e., *Deflated air volume + Pot-MAV < 60cmH₂O*, Thus *Pot-MAV = Prac-MAV*.) The mean volume which made CP to 60cmH₂O were size 3: 3.6mL, size 4: 4.0mL, and size 5: 5.2mL. These were employed as Pot-MAV for further investigation.

Phase 2:

The mean volumes of deflated air to reach 20cmH₂O below zero were Size 3: 13.3mL, Size 4: 18.2mL and Size 5: 24.8mL. Figure 4 illustrates CP measured when the LMA was inflated with 'deflated volume plus pot-MAV'. In the measurement using Size 3 LMAs, approximately half (i.e., median) did not exceed 60cmH₂O. In cases of Size 4, only 25% were below 60cmH₂O. Less than 25% fell into the category of <60cmH₂O for Size 5 LMAs. In a word, majority of CPs exceeded recommended maximum pressure when inflated with pot-MAV regardless their sizes.

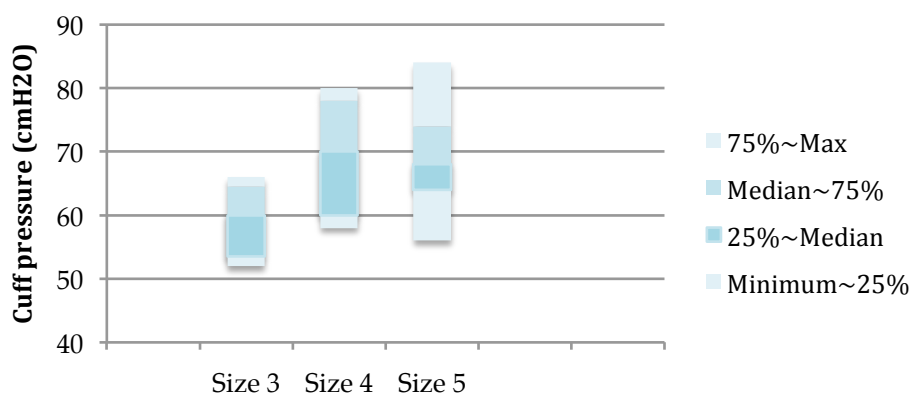


Figure 4: CP on hypothesis testing

Each colour gradation indicates percentile ranks

Table 4 summarises the results of the post-hypothesis measurements. CPs reach 60cmH₂O by adding significantly smaller volume compared to Pot-MAV. Amongst 6 set volumes, 2mL was the only volume, which maintained CP below 60cmH₂O for size 3 LMAs. Similarly, 2.5mL for size 4 and 3.5mL for size 5, kept CPs close to but not exceeding 60cmH₂O. These volumes are significantly lower compared to Pot-MAV², thus the hypothesis was rejected.

Table 4: Intra-cuff pressure (CP) in cmH₂O after inflating with set air volumes

Air volume	2mL	2.5mL	3mL	3.5mL	4mL	4.5mL
	Mean (Range)	Mean (Range)	Mean (Range)	Mean (Range)	Mean (Range)	Mean (Range)
Size 3	50.3(48-52)	58.7 (50-68)	63.7 (56-72)	79.4 (70-92)	84.9 (76-93)	99.7(90-111)
Size 4	45.1(44-46)	50.8 (44-59)	59.7 (50-69)	73.9 (64-90)	83.1 (68-104)	93.6 (80-114)
Size 5	34.4 (32-38)	48.1 (44-54)	48.4 (43-56)	56.6 (52-59)	68.1 (59-77)	75.7 (62-82)

It is worthwhile noting that the LMAs became flat and wrinkle free before their CP reached 20cmH₂O below zero. Figure 5 shows the shapes of LMAs when their CP reached at 20cmH₂O below zero while Figure 6 shows cuff shapes when they were deflated with 10mL, 12mL and 15mL of air.



Figure 5: LMAs at CP of 20cmH₂O below zero



Figure 6: LMAs deflated with 10mL (Size 3), 12mL (Size 4), and 15mL (Size 5)

Discussion

Rejected hypothesis

Pot-MAVs were not employable as they failed to keep CPs under optimal maximum pressure consistently. The reason for this hypothesis rejection is not clear, however, following reasons are considered as possible cause. First, the number of the LMAs used in this study was not large enough, thus employing means of these measurements as MAV was not sufficient to generalize. Second, the material used to form cuff part was not consistent. The LMAs were manufactured satisfying the manufacturer's standard, however, the thickness and/or the extensibility of the cuff may not have been uniform. As a result, LMAs had individual differences, which may have led the initial hypothesis to be rejected. Should LMAs have relatively large individual difference, the risk of over-inflation would be high unless Prac-MAV is set at almost universally safe level.

Suitable syringes

CP increases significantly even if a small volume of air is added. CP easily increases more than 10cmH₂O by adding as little as 0.5mL of air. On inflation, air volume should be controlled carefully using a syringe which has large gradation. Results of Phase 1 indicate that volume is to be controlled at most 0.5mL increments.

² The Chi-square test was used to test significance at probability level of .005.

Therefore, 50~60mL syringes are not suitable as the scale of the incrementation is too great to control minimal flow of 0.5mL of air, thus have high risk of inflating large volume of air. Figure 7 shows gradations of variety of syringes. Large syringes such as 50~60mL are also not recommendable as that inflation with a 60mL syringe caused greater residual pressure compared to that with a 30mL syringe (16).

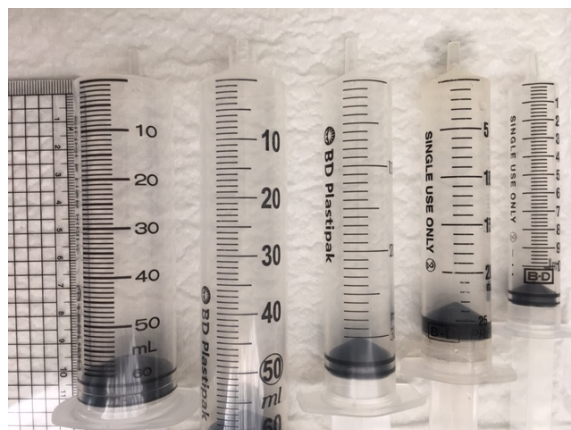


Figure 7: Comparison of gradations of syringes

(Left to right: Terumo 60mL, BD 50mL, BD 30mL, BD 20mL, and BD 10mL)

Deflating LMAs

During Phase 2, LMAs were ‘flattened’ until their CP reached minus 20cmH₂O below zero. However, it is not necessary to remove large volume of air in order to deflate the LMA. As shown in Figure 6, cuffs become ‘flat and wrinkle free’ after deflating 10~15mL of air depending on the size. These volumes are remarkably smaller than volumes which made LMA CP minus 20cmH₂O below zero. In other words, cuffs deflated with 10~15mL of air satisfy instructions shown in several resources. They are deflated ‘until the distal end of the cuff is curled anteriorly’ [26] or ‘with the rim facing away from the mask aperture, no folds near the tip, wrinkle-free’ [22]. Two factors should be considered in determining ideal deflation. Based on the findings from Phase 1, 20~30mL syringes are the most suitable to control air volume, thus deflating volume should be limited within these syringes’ controllable range. Furthermore, deflating LMAs by removing large volume of air makes LMAs flat but with wrinkles and possibly creates residual negative pressure in the masks. Therefore, deflating volume should be minimal, not exceeding 16~26mL³ so that the syringe still maintains its capacity to accommodate Prac-MAV.

Inflating air volume : Prac-MAV

This study found that CP of the LMA becomes close to 60cmH₂O by adding ‘deflated air volume plus Prac-MAV’. In case of size 3 LMAs, Prac-MVA is 2.0mL. Similarly, Prac-MAVs for size 4 and size 5 LMAs are 2.5mL and 3.5mL, respectively. These volumes are far smaller than maximum air volume recommended by the manufacturer. It should be noted that these Prac-MAV are determined in ex-vivo (i.e., free room) circumstance, therefore, when the LMA is in-situ, MVA will be even smaller due to each patient’s anatomical structure and/or other factors [13]. Despite the ‘maximum air volume’ recommended by the manufacturer, volume must be much smaller in order to achieve optimal CP range. In other words, inflating the LMA following manufacturers’ instruction is highly likely to cause significant hyper-pressure. This finding well supports previously conducted studies which reveal discrepancies between suggested volume and actual CP. [10,14,18]

Conclusion

This study found that both instructions seen in related resources and manufacturers’ instruction at the back of the package are not specific and have a risk of causing over-inflation at the preparation and insertion of the LMA. As CP increases during the procedure (13, 17), patients are likely to experience sore throat or even

³ 20mL syringe : syringe capacity 20mL – (Largest Prac-MAV 3.5mL + reserve 0.5mL) = 16mL

30mL syringe : syringe capacity 30mL – (Largest Prac-MAV 3.5mL + reserve 0.5mL) = 26mL

more serious complications post-operatively. This study resulted in forming a model of practical methods to reduce the risk of over-inflation. Even though this study has been conducted using LMAs of a particular brand (i.e., *PRO-Breathe*), mask sizes across any types of LMAs as well as any brands of LMAs should not be significantly different, as long as they are of the same size. Thus the suggestions below would be reasonably applicable for all LMAs for adult patients.

The following are suggested as a *practical guide*:

- (a) Use a 20~30mL syringe with reasonably big gradation.
- (b) Prior to the insertion, deflate the LMA until mask is flattened by aspirating no more than 16mL (with a 20mL syringe) or 26mL (30mL syringe) of air and note the volume.
- (c) After the insertion, inflate the LMA until air leak stops by controlling the air volume by 0.5mL increments but not exceeding deflated volume plus Prac-MAV (Size 3: 2mL, Size 4: 2.5mL, Size 5: 3.5mL).
- (d) Be aware that 'deflated volume plus prac-MAV' may still exceed 60cmH₂O.

It is predictable that air volume exceeding Prac-MAV may be required in order to obtain sufficient air seal depending on each case, however, anaesthetists and anaesthetic assistants need to be aware that such practice is highly likely to cause significant hyper CP. Most importantly, these suggestions should never substitute the use of proper CP gauge and continuous monitoring of CP during the procedure. Use of proper CP gauge and continuous CP monitoring during procedures are always recommended wherever possible.

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