Southern African Journal of Anaesthesia and Analgesia 2018; 24(5):145–147
https://doi.org/10.1080/22201181.2018.1517475

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

LETTER

The effect of different anaesthetic mask shapes on the anatomical dead space using infant, child and adult part-task trainers

L Botes[a], J Jacobs[a], R Rademeyer[a], S Van der Merwe[a], L Van Heerden[a] and BJS Diedericks[b*]

[a]*School of Medicine, University of the Free State, Bloemfontein, South Africa*
[b]*Department of Anaesthesiology, University of the Free State, Bloemfontein, South Africa*
**Corresponding author, email: diedericksbjs@ufs.ac.za*

Dead space is the portion of tidal volume that does not participate in alveolar gas exchange. The purpose of this study was to compare the dead space contribution of differently shaped masks, of the same size, by measuring the volume of each mask. The study was conducted in the Clinical Simulation Unit of the School of Medicine, University of the Free State (UFS) using formed masks with inflatable polyvinylchloride (PVC) cuffs and rounded masks with non-inflatable PVC cuffs. The masks were placed on the faces of the infant, child and adult part-task trainers as well as on a flat surface. The cuffs of the formed masks were inflated to 5 cm water and 70 cm water. Masks were filled with water and the volume was measured.

The volumes (ml) of the masks on the flat surface were significantly larger than those measured on the part-task trainers' faces. The volume of the rounded masks was greater than the volume of the formed masks. The amount of cuff inflation pressure (5 cm water vs. 70 cm water) did not lead to a significant change in mask volume: 102.3 ml (standard deviation [SD] 75.9) vs. 110.2 ml (SD 82.3), averaged for all sizes.

Formed masks contribute less to anatomical dead space than rounded masks and are thus possibly the better choice. Cuff inflation pressure has insignificant influence on dead space volume.

Keywords: anaesthesia, anatomical dead space, inhalation, masks, pulmonary ventilation, respiratory

Introduction

Dead space is the volume of air that does not participate in alveolar gas exchange during ventilation.[1] During normal respiration, in a resting state, physiological dead space is present. Physiological dead space consists of anatomical and functional/alveolar dead space. In a normal person, the physiological and anatomical dead space are approximately equal. Functional dead space from alveoli with little or no blood supply is negligible. During administration of anaesthesia, the dead space is affected.[2] It is important to minimise dead space for the prevention of re-breathing that will result in hypercarbia, especially in infants and children. The most common result of an increase in physiological dead space is an increase in the concentration of the partial pressure of carbon dioxide ($PaCO_2$), which will increase acidity of blood and decrease the pH level. In order to compensate for the increase in dead space, minute volume must be increased to maintain a normal $PaCO_2$.[3] With large anatomical dead space neither increased gas flow nor increased minute volume may be enough to prevent re-breathing.

Different factors contribute to the increase in dead space during the administration of anaesthesia: the volume contributed by a mask, an artificial airway, and the position of the head. Age also has an effect since infants and children have smaller alveoli and chest wall collapse may reduce anatomical dead space if negative intrathoracic pressures are reduced.[4] In a normal healthy person, dead space can be estimated at 1 ml/pound (2.2 ml/kg) of body weight, but that has been shown to be inaccurate.[5] The dead space to tidal volume ratio in healthy lungs is constant at about 0.3. An increase in total dead space is more critical in infants than in adults because children have smaller tidal volumes.[2] Thus, any contribution to the amount of dead space is important and should be minimised as it may lead to serious consequences, such as hypercapnia, dysrhythmias and even cardiac arrest.

At the Bloemfontein Academic Hospital Complex, formed masks with an inflatable polyvinylchloride (PVC) cuff and round, domed masks with a non-inflatable PVC cuff are used. Domed masks may be easier to manufacture and are without an inflatable cuff, making them cheaper. Inflation of the cuff may increase or decrease the mask's dead space. According to Smith's *Anesthesia for Infants and Children*,[2] paediatric face masks should be constructed with clear plastic that allows inspection for cyanosis and should also fit the face without a leak. Various types of face masks are available, but the most commonly used is the plastic disposable mask that contains an inflatable cuff. The appropriate size mask should rest on the bridge of the nose and extend to the mandible.[2] During anaesthesia, dead space should be limited for the reasons already mentioned.

Aim

The aim of this study was to measure and compare the contribution made to anatomical dead space by formed and rounded masks of similar sizes (Supplementary figure 1) in order to determine which type of mask contributes the least volume. An additional objective was to determine the effect of cuff inflation pressure on the volume of formed masks.

Methods

This was an experimental study. The study was done using the infant, child and adult part-task trainers in the Clinical Simulation Unit of the School of Medicine, University of the Free State (UFS). No patients were involved in the study.

Two types of masks were used: formed masks with inflatable PVC cuffs and rounded masks with non-inflatable PVC cuffs. These types of masks, provided by the Department of Health, are used at the Academic Hospital Complex, Bloemfontein. The formed masks came in six sizes (00, 02, 04, 06, 08 and 10) and the rounded masks in three sizes (00, 02 and 04). At the time of the study, the three adult-sized rounded masks were no longer being produced.

Different scenarios were created to measure the volume of the six different-sized formed masks. The cuffs of the formed masks were inflated to 5 cm water (resulting in a soft air-filled cushion) and 70 cm water (resulting in a firm stiff cushion), respectively. Pressure was measured with an aneroid cuff inflator device. The mask volumes were determined while the formed masks were pressed on the part-task trainers' faces and again on a flat surface. Because of the standard stiff cuff of the rounded masks, adequate fit could not be attained. Even with excessive force, mask leak could not be prevented. Thus, mask volume for the rounded masks was only determined using a flat surface. The formed masks fitted watertight to the part-task trainers without the need for much force.

Measurements

The nasal and oral openings of the three part-task trainers were sealed with a temporary putty-like adhesive to improve the accuracy of the measurement. The volume was determined while the mask was on the part-task trainer's face to account for factors such as the volume of the nose and lips. External pressure was applied to the masks for the measurements on a flat surface.

The masks were filled to the rim with water from a volumetric flask using different-sized syringes with a specific volume of water. The volume inside the mask was determined by subtracting the remaining volume in the volumetric flask from the original volume.

The volume of each mask was measured by three student researchers under the supervision of the study leader. The results were recorded on a data sheet.

Pilot study

A pilot study was done using the infant part-task trainer in the Clinical Simulation Unit of the School of Medicine, UFS, to check the methods and instruments. Three student researchers each measured sizes 02 and 04 masks, which are appropriate for use on an infant, thus measuring the volume of the formed and rounded masks in the different scenarios. During the filling of the masks with water, different methods of sealing the masks to prevent leakage were tested. The putty-like adhesive and external pressure were the methods that resulted in no leakage. The data from the pilot study were included in the main study.

Data analysis

The results were entered into an Excel® spreadsheet (Microsoft Corp, Redmond, WA, USA). The mean of the three values from the three different students was used to improve the accuracy. Results were summarised by means and standard deviations. Paired t-tests were used to compare mask types, with significance level set at 5%. Masks of the same size were compared in terms of volume, thus for the three largest sizes only formed masks were compared, whereas the rounded and formed masks were compared for the three smaller sizes.

Ethical aspects

The study was approved by the Health Sciences Research Ethics Committee (HSREC), UFS [HSREC-S 25/2016]. Permission was obtained from the Clinical Simulation Unit, School of Medicine, UFS, to use the facility and its part-task trainers.

Results

Table 1 gives the volumes of different formed mask types and sizes on the part-task trainer' faces and on the flat surface. The volumes (ml) of the masks on the flat surface were significantly larger than those measured on the part-task trainer' faces (5 cm p-value = 0.02; 70 cm p-value = 0.01). Masks with cuffs inflated to 70 cm water had a larger volume than masks with cuffs inflated to 5 cm water, but not significantly so (on part-task trainer p-value = 0.07; flat surface p-value = 0.16).

Table 2 gives the volumes of the rounded masks for the three sizes for which these marks were available, as well as for the corresponding formed masks.

The volume of the rounded masks was more than the volume of the formed masks (Table 2), but not significantly so (p-values ranging from 0.14 to 0.25).

Table 1: Volumes of different mask sizes of formed masks on the faces of the part-task trainers and on a flat surface

	On the part-task trainers (ml)		Flat surface (ml)	
	Formed mask, inflated		Formed mask, inflated	
Size	5 cm water	70 cm water	5 cm water	70 cm water
00	20	20	24	26
02	30	32	44	44
04	66	66	94	96
06	130	148	187.5	204
08	158	175	205	213
10	210	220	228	280
Mean	102.3	110.2	130.4	87.7
SD	75.9	82.3	143.8	103.0

SD = standard deviation.

Discussion

Mask on face compared with mask on a flat surface

As expected, the volume of the nose, lips and facial contours has a significant influence on the volumes by decreasing the volume.

Cuff of formed mask inflated to 5 cm water compared with 70 cm water

The difference between the volumes of a formed mask inflated to 5 cm water compared with a formed mask inflated to 70 cm water was not large enough to be statistically significant. Though the formed masks fit well on the face (or part-task trainer), the slightly greater pressure needed for a tight fit with higher cuff inflation pressures may decrease dead space for that mask.

Rounded masks compared with formed masks

The volume of the rounded masks was greater than the volume of the formed masks (but without statistical significance). This is

Table 2: Volumes of different mask sizes of formed masks on the faces of the part-task trainers and on a flat surface, compared with rounded masks of similar sizes on a flat surface

	On the part-task trainers (ml)		Flat surface (ml)		
	Formed mask, inflated		Formed mask, inflated		Rounded mask
Size	5 cm water	70 cm water	5 cm water	70 cm water	
00	20	20	24	26	25
02	30	32	44	44	52
04	66	66	94	96	102
Mean	38.7	39.3	54.0	55.3	59.7
SD	24.2	23.9	36.1	36.4	39.1
p-value*	0.14	0.15	0.14	0.25	

SD = standard deviation.
*Comparison with rounded mask.

expected, as the formed masks are designed to fit the face contour closer and consequently have a smaller volume, thus making a smaller contribution to dead space. The cuff of the rounded masks cannot be inflated, which likely makes manufacture simpler and cheaper. As the unyielding cuff of the rounded mask makes a tight fit more difficult, the pressure necessary in attempting to improve fit may reduce dead space. On the part-task trainers, a tight fit could not be established for the rounded masks, but it may be possible on the softer facial tissue of a child. However, in practice, one would avoid pressing down hard with a mask, which may increase a feeling of claustrophobia and may cause tissue damage.

Study limitations

The sample size was smaller than planned because the three adult-sized rounded masks were no longer being produced. Only three sizes of the rounded masks were available.

To achieve an effective seal between the mask and the surface on the part-task trainers' faces, an external force had to be applied. This decreased the volume of the mask, especially in the rounded masks, to the extent that readings would be unreliable if they were taken on the part-task trainer's face; therefore, rounded mask measurements were only taken on a flat surface.

Water was used instead of air to measure dead space.

Since only a limited number of masks (one of each size) were tested, differences in manufacturing quality could not be detected. A further study may investigate the quality and reliability of masks supplied to the hospital.

Conclusions

Applied external force decreases the volume of the mask. Formed masks contributed less to dead space than rounded masks. Inflation pressure of plastic cuffs has, on average, insignificant effect on dead space volume.

Recommendations

- Apply a standard amount of force in each measurement as external force applied has an influence on the measurement.
- The difference between the volume of inflation to 5 cm of water on face vs. 70 cm of water inflation on face, which was close to significant in this study, could be researched in future studies.
- A larger number of the same-sized marks could be investigated for consistency of findings.

Acknowledgements – The authors thank the participants of the study, Dr MJ. Labuschagne and the Clinical Simulation Unit of the School of Medicine, UFS, the MSSM lecturers for guidance, Mr J de Wet, Department of Mathematical Statistics and Actuarial Science, UFS, and Prof G Joubert, Department of Biostatistics, UFS, for statistical analysis, Mrs L Berlyn, Medical Telefex, for donating the masks used during the study, and Ms T Mulder, medical editor, School of Medicine, UFS, for preparation of the manuscript.

Conflict of interest – The authors declare that they have no financial or personal relationship(s) which may inappropriately influenced them in writing this paper.

Supplemental data – Supplemental data for this article can be accessed https://doi.org/10.1080/22201181.2018.1517475.

ORCID

BJS Diedericks http://orcid.org/0000-0003-2543-2996

References

1. Miller R, ed. Miller's Anesthesia. 8th ed. Philadelphia, PA: Churchill Livingstone; 2015.
2. Davis P, Cladis F, Motoyama E, eds. Smith's Anesthesia for Infants and Children. 8th ed. Philadelphia, PA: Mosby; 2011.
3. Lieberman M, Peet A. Marks' Essentials of Medical Biochemistry. A Clinical Approach. 2nd ed Philadelphia (PA): Lippincott, Williams & Wilkins; 2015.
4. Pasternak LR. ASA practice guidelines for preanesthetic assessment. Int Anesthesiol Clin. 2002;40(2):31–46.
5. Brewer LM, Orr JA, Pace NL. Anatomic dead space cannot be predicted by body weight. Respir Care. 2008;53(7):885–91.

Received: 25-04-2018 Accepted: 27-08-2018