Dead Space Variability of Face Masks for Valved Holding Chambers

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Abstract

Background: Valved holding chambers with masks are commonly used to deliver inhaled medications to young children with asthma. Optimal mask properties such as their dead space volume have received little attention. The smaller the mask the more likely it is that a greater proportion of the dose in the VHC will be inhaled with each breath, thus speeding VHC emptying and improving overall aerosol delivery efficiency and dose. Masks may have different DSV and thus different performance.

Objectives: To compare both physical dead space and functional dead space of different face masks under various applied pressures.

Methods: The DSV of three commonly used face masks of VHCs was measured by water displacement both under various pressures (to simulate real-life application, dynamic DSV) and under no pressure (static DSV).

Results: There was a great variability of both static and dynamic dead space among various face mask for VHCs, which is probably related to their flexibility.

Conclusions: Different masks have different DSV characteristics. This variability should be taken into account when comparing the clinical efficacy of various VHCs.

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In young children and infants and in the elderly and infirm or mentally challenged who cannot breathe through a mouthpiece, the face mask serves as the interface between the patient and the valved holding chamber. Although the mask interface is one of the most important factors determining the dose of medication delivered from the VHC to the nose and mouth in these patients, its optimal characteristics are not well known.

One of the factors involved in mask efficiency is the volume of air common to the inspiratory and expiratory pathways, namely the dead space volume. Any drug contained in that volume will be lost on expiration and will not contribute to the lung dose. The smaller the mask dead space volume the more likely it is that a greater proportion of the dose in the VHC will be inhaled with each breath [1], thus speeding VHC emptying and improving overall aerosol delivery efficiency and dose. A distinction should be made between the physical dead space of the mask (static) and its functional dead space. By this, we mean that when a mask is applied to the face, the variable pressure applied causes compression of the mask and a variable reduction in the mask dead space. For any given applied pressure, mask flexibility will be a major determinant of the mask compressibility and dead space.

Masks may have different DSVs, resulting in different performance. The purpose of the present investigation was to compare both physical dead space and functional dead space of different face masks under various applied pressures.

Materials and Methods

Three of the most commonly used VHC masks in Israel were studied, as was a single anesthesia mask (Hans-Rudolph, Kansas City, MO USA). The VHC masks included those provided with the Aerochamber (Trudell Medical, London ON, Canada), Nebuchamber (AstraZeneca, Lund, Sweden) and Babyhaler (Glaxo GmbH, Germany) VHCs. Dead space volume and the change in volume of the face masks (without their VHCs) were evaluated under in-use conditions using a life-size doll's head representing a 10 kg infant (approximately 1 year old). The data were collected by filling the face masks with water and determining their "resting" volume by means of a calibrated pipette. They were then placed on a horizontal surface with their concave surface facing upwards, and the doll's face was introduced from above. Pressure was applied initially with a 0.5 kg ("light" pressure) mass and subsequently with a 2.5 kg ("heavy" pressure) mass placed on the back of the doll's head. This range was selected from pre-study measurements of the forces generated under similar laboratory settings by one of the authors, an experienced pediatric pulmonologist who routinely demonstrates face mask application to parents. The displaced water representing the reduction of mask dead space and the volume of water that remained were measured with a volumetric flask [2]. Each measurement recorded represents the mean of five determinations under each of the three experimental conditions – "rest," "light pressure" and "heavy pressure." Special attention was paid to mask positioning to ensure a complete seal between the mask and the doll's face in all experiments.

Results

Figure 1 shows the physical dead space under no pressure and at various applied pressures. Figure 2 shows the percentage change of volume in each of the masks at maximum applied pressure. While the physical dead space ("rest" conditions in Figure 1)

VHC = valved holding chambers
DSV = dead space volume
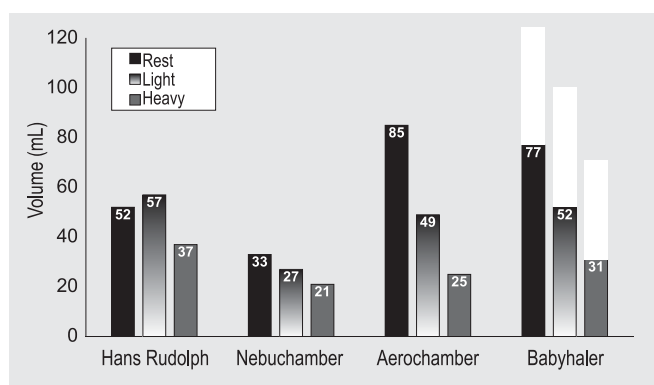
Figure 1. Dead space volume (mean ± SD) of commonly used face masks at rest and at various applied pressures (see text). White (empty) bars in Babyhaler represent the fixed valve compartment dead space.
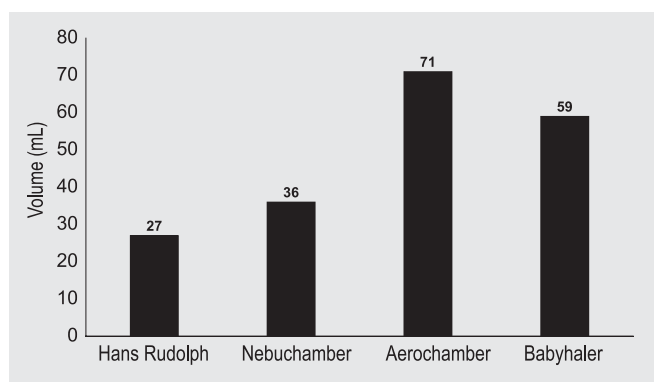
Figure 2. Relative (%) change (mean ± SD) in volume of face masks at maximum applied pressure.

varied significantly ($P < 0.01$) between all the different masks, the variability decreased (but remained significantly different, $P < 0.05$) when pressure (in the Figure, light or heavy) was applied. The more compressible the mask, the greater the difference between the physical and functional dead space. A maximum reduction of dead space volume (71%, $P < 0.01$ versus all other masks) was seen with the Aerochamber mask [Figure 2], whereas the Hans Rudolph facemask was relatively inflexible.

Discussion

This *in vitro* study demonstrated that there is great variability of both static and dynamic dead space among three commonly used face masks for VHCs. It confirms the results of a recently published study of seven face masks for VHCs [3]. When aerosol delivery by the VHC is evaluated, the dead space factor should be taken into account. Aerosol delivery is highly dependent on dead space, and the smaller the dead space the more aerosol will be delivered per breath. This is particularly important in neonates and infants under 1 year old as well as toddlers or children with low tidal volume. The tidal volume ranges from 10–20 ml in neonates to 25–100 ml in infants up to the age of 18 months [4] Thus, in practice, with the Babyhaler's 77 ml mask static dead space to which must be added a fixed 40 ml valve

chamber dead space for a total of 117 ml, it is predictable that only minimal amounts of drug would be delivered to the nose or mouth of infants younger than 1 year of age. With older infants, the mask dead space decreases as the infant's face grows and fills the mask, while their tidal volume increases. As a result, the dead space to tidal volume ratio improves and aerosol delivery becomes progressively more efficient [1].

While there are different designs of face masks that result in different dead space volumes under static conditions, the dynamic behavior of masks, namely their decrease in dead space volume following application to the face, also varies considerably. The major factors affecting changes in dead space are the pressure applied by the caregiver, usually a parent or nurse, and the flexibility/compressibility of the mask. Stiff masks will resist compression by the infant's face so that the reduction in dead space will potentially be much less than with compressible masks. With regard to the relative compressibility of various masks, it can be seen that there is considerable variability [Figure 2]. The Hans Rudolph mask, for example, is very stiff, its physical dead space being reducible by only 27% when greater pressure is applied. Increasing compressibility is seen with the Nebuchamber, Babyhaler, and Aerochamber masks respectively, the latter being most compressible.

With all the masks, dead space decreases with increasing pressure. However, application of the face mask to young children and infants is inherently problematic [5]. Ritson et al. [6] suggested that the applied pressure needed to achieve a mask-to-face seal in their patients often induced distress and affected the efficiency of aerosol delivery. Similarly, Marguet and co-authors [7] demonstrated that crying occurred in 38% of their young patients receiving inhaled therapy administered via face masks. Thus, the benefit of increased pressure and reduced dead space may be offset by the infants' distress. Using a highly compressible mask, allowing a greater reduction in dead space even at relatively low applied pressures, is the ideal solution and every effort should be made to design masks that are highly compressible.

On the other hand, excessive compressibility may result in mask prolapse as pressure is applied, making the design of the shank of the mask or the supporting collar very important. Flexibility/compressibility is determined by many factors, the most important of which are the characteristics and thickness of the silicone plastic used for the body and shank of the mask which may not be identical, and mask dimensions. The thinner the walls, the greater the flexibility. However, if the material is too thin the body of the mask may collapse and become distorted, thereby breaking the face-mask seal or allowing in-mask exhalation valves to leak when pressure is applied. Repeated excessive flexing may also shorten mask durability.

The current study was not a clinical study. As previously discussed, application of face masks to babies during real life together with quantification of the dose of drug delivered to the lungs from pressurized metered-dose inhalers, using various applied mask pressures, would be extremely difficult if it could be accomplished at all. The present study has, however, demon-

strated that by using a surrogate of a 1 year old infant, namely a doll's head, the application of various pressures applied to masks of varying compressibility could result in poor aerosol delivery if the infant's tidal volume is relatively small and the mask dead space relatively large due to poor compressibility or low applied pressures.

The best current mask designs are reasonably efficient, but additional studies should be undertaken to make them more patient- and caregiver-friendly in order to minimize anxiety and resistance to therapy by small children and infants.

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