Review Article

NEW DEVELOPMENTS IN THE MANUFACTURE OF LOW-COST MODIFIED BOTTLE SPACERS

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ABSTRACT

Metered dose inhalers (MDIs) are the devices most commonly used to deliver aerosols to the lungs. With optimal technique, lung deposition averages below 10% rising to approximately 15% if a spacer is used. Optimal hand–breath coordination is required when using MDIs directly in the mouth as actuation one second before inhalation reduces drug delivery by 90%.[1] Spacers and valved holding chambers provide an additional volume in which medication is dispersed before it is breathed into the lungs. Because particles are breathed in after dispersing within the chamber, both aerosol velocity and particle size are reduced as larger particles adhere to the sides of the chamber. These factors prevent most of the deposition on the oropharynx and improve lung deposition by approximately 6% (from 8.8% to 14.8%).[2] Despite the widespread misconception that nebulisers work better than MDIs even with spacers, metered dose inhalers can achieve equivalent, or even better clinical effect than nebulisers, simply by increasing the number of puffs to deliver the same dose. Cochrane reviews show an equivalent risk of hospital admission for adults whether treated with nebuliser or MDI but a 35% reduction in risk of admission for children when treated with MDIs.[3] In children, the length of stay in emergency departments is significantly shorter when an MDI and spacer is used with a mean difference of almost 30 minutes.

Keywords: low-cost modified bottle spacers, metered dose inhalers

INTRODUCTION

The use of a modified 500 mL plastic bottle as an asthma spacer was pioneered by Professor Heather Zar in the 1990s. This concept, now dubbed the 'AfriSpacer', began with a hole burned in the bottom of plastic bottles in the shape of a standard MDI's mouthpiece.[4] Research conducted at the Red Cross War Memorial Children's Hospital evaluated the efficacy of using plastic bottle spacers, demonstrating that they are as effective as commercial spacers for improving oxygen saturation, peak flow rates and clinical scores, while reducing the need for additional treatment and hospital admissions in acute asthma.[5,6]

Burning holes in the bottom of plastic bottles releases toxic fumes and results in carbon being deposited in the base of the bottles. This process is time-consuming and labour-intensive, limiting the production to small numbers. An alternative method of softening the mouth of the bottle in boiling water as the point of insertion of the MDI and cutting the bottle in half to fashion a rudimentary mask is not feasible (the MDI cannot be made to fit into the mouth of a bottle). This is also ineffective as the hard surface of the cut bottle, even with padding, cannot be made to seal over an infant's face.[7] In 2019 a new solution was proposed by biomedical engineering students at the University of Cape Town in which the elliptical shape of the MDI mouthpiece was cut from the base of the bottle using a Dremel drill with a specially made rig. This solution worked well for small batch numbers of up to 1 000 but was labour-intensive and not cost-effective or sustainable in the long run.

At the onset of the COVID-19 pandemic in early 2020, the risks of using a nebuliser to deliver inhaled therapy were again thrust to the fore. Nebulisers have a high risk of SARS-CoV-2 transmission as they can produce droplets in the small- and medium-size aerosol range[8] and disperse viral particles in exhaled air > 0.8 m from the patient that may remain airborne for more than 30 minutes.[9] This led to recommendations to use MDIs with inhaler therapy, rather than nebuliser therapy, as the default therapy in all asthmatics in all circumstances apart from immediately life-threatening asthma.[10] Implementation of this recommendation was limited by the increased demand for and insufficient numbers of low-cost spacers, particularly in the public health service. We therefore wished to produce large numbers of spacer rapidly and make them available to primary-care sites.

In order to make a rapidly scalable version of the AfriSpacer, Polyoak developed an idea of blow-moulding the bottles with a modification at the base to allow more rapid conversion into a spacer. We therefore designed and produced a mould for the base of the blow-moulding machine used to make the bottles directly at manufacture. During the blow-moulding production process, the plastic of the bottle is still soft, and air is blasted into the bottle base which contains an extrusion in the exact size and shape of the inhaler's mouthpiece. This results in a protuberance in the shape of the inhaler. After that, the only manual task is to slice off the end of the protuberance leaving a perfect-fit hole for attaching the inhaler.

Figure 1: The base for the blow-mould machines

Figure 2: The bottle spacer as produced with the protuberance

The blow-moulding process creates a cleaner final product that is cost-effective and easily scalable to produce large numbers of spacer. During 2020 and early 2021, funding solicited from the ELMA Philanthropies allowed the Allergy Foundation of South Africa (AFSA) to produce and deliver 100 000 spacers to five provinces of South Africa (30 000 to Western Cape, 20 000 to Gauteng, KwaZulu-Natal and Eastern Cape, 10 000 to North West province). The spacers were delivered to central medicine depots allowing distribution of spacers to any health site within these provinces using the provincial ordering mechanisms.

Challenges that were encountered along the way included post-processing of the bottles to cut off the protuberances and adding instructions for use to the spacers. Initially, a more effective method of removing the protuberance was devised by producing a cutting machine comprising a wood lathe in a cradle that is capable of cutting a box of 170 bottles in ten minutes. This method produces a clean edge that produces no dust or burrs and requires no cleaning. Subsequently, the biomedical engineering students at the University of Cape Town, with their company Impulse Biomedical, produced a second solution allowing multiple bottles to be loaded into a cradle and pushed over a lathe simultaneously, further reducing the post-production processing time.

Figure 3: The protuberance is cut off to produce the hole for the asthma pump

Figure 4

Figure 5

The second challenge was providing instructions for the use of the spacer. This was achieved by designing labels printed with instructions for optimal use. Cape Town-based Maker Station designed and produced five labelling machines to semi-automate the process and reduce the processing time required to affix labels.

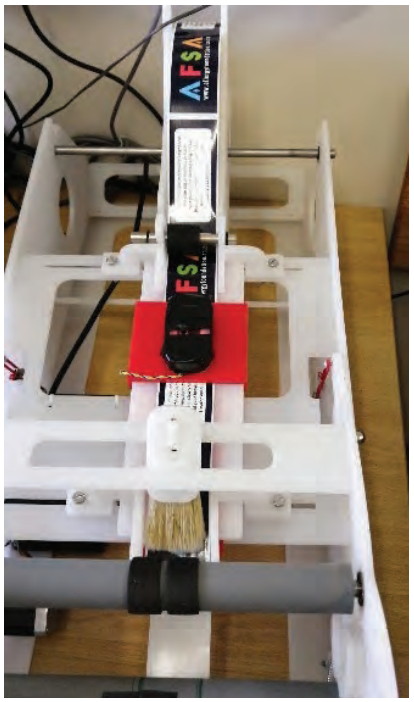

Figure 6: Labelling machine

Figure 7: AfriSpacer version 1

NEXT STEPS

From burning elliptical holes in plastic cooldrink bottles, to milling them, and now blow-moulding the base of the spacer, the AfriSpacer has come a long way in the past year. However, the major barrier to increase the scale of the project and ensure its long-term viability remains the post-processing of the bottles, including the cutting of the protuberances and the labelling. Alternatives to the labelling process were therefore considered. Because bottles are usually labelled while standing on their bases, the protuberance at the base of the AfriSpacer makes them unsuitable for this process. In addition, printing directly on a corrugated section of bottle is very difficult. The second version of the AfriSpacer will therefore use a different bottle with a non-corrugated section which will allow the instructions to be printed directly on the bottles during the production process, completely eliminating the separate labelling step.

Spacers can be used in two very different ways. The most effective technique involves breathing all of the air out of one's lungs to as close to residual volume as comfortable. This is followed by actuating the MDI into the spacer, breathing all of the medication containing air slowly and deeply into one's lungs, followed by a breath-hold of ten seconds and then slow exhalation through the nose. This 'single-breath inhalation technique' may not be possible in young children, older adults and those with respiratory impairment. The alternative technique is to breathe slowly in and out of the spacer's mouthpiece, for at least six deep tidal breaths. If a spacer is to be used with this technique, a one-way valve is required to divert exhaled air away from the bottle and prevent it from dispelling uninspired medication-containing air. The spacer's effectiveness is markedly limited with this technique if a valve is not present.

In order to address this problem, a one-way valve system was developed that clips onto the mouthpiece of the AfriSpacer. This device, dubbed 'AfriValve', is a cost-effective injection-moulded valve system that allows patients to keep their mouths on the mouthpiece while inhaling and exhaling. The system ensures comfortable and efficient delivery of medication to the patient. The AfriValve can be mass manufactured easily and is a scalable solution. The use of the AfriValve with the AfriSpacer improves its efficacy to have identical functionality

Figure 8: The AfriValve attached to an AfriSpacer

to commercial spacers at a fraction of the cost. The valve will be manufactured using medical plastics and silicone and will be washable at high temperatures making it a safe, effective and durable product.

The AfriValve consists of two injection-moulded polypropylene plastic parts and a flat silicone membranous valve stamped from a sheet of silicone rolled out to our desired thickness that is used to create unidirectional flow of air. All components are designed to minimise manufacturing costs and improve the functioning of the AfriSpacer for improved delivery of medication.

Figure 9: The three components of the AfriValve prototype manufactured using a 3D printer and cast silicone

During inhalation, the membranous valve (shown in red) pushes upward and allows medication-filled air to travel through to the patient's mouth. During exhalation, the valve closes, preventing air from entering the bottle, but it opens an exhaust, allowing the exhaled air to travel outside of the bottle (see Figure 10).

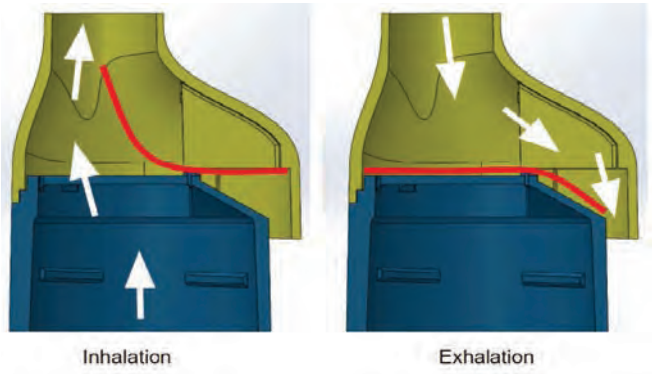

Figure 10: How the two-directional valve functions during inhalation (left) exhalation (right)

The AfriValve prototype has worked well thus far and has completed a second phase of design iteration to ensure that the membranous valve is the correct thickness and hardness/stiffness. "AFSA has secured funding via the Water Institute of South Africa (WISA) from Grundfos, and additional funding from ELMA philanthropies, which has allowed us to employ a manufacturer to move to mass manufacturing."

Figure 11: AfriValve renders in various colour combinations

Figure 12: The AfriSpacer and the AfriValve

The AfriValve is projected to have the greatest impact in low- and middle-income settings and lead to markedly reduced costs of spacers, thereby improving the availability of efficient emergency and chronic asthma treatment. This aims to improve chronic control, leading to fewer unscheduled hospital visits and reduced admissions. In addition, the widespread availability of spacers for the management of acute asthma will reduce the need for nebulisers and therefore prevent spread of infectious diseases that are facilitated by droplet spread when using nebulisers. The AfriValve has been patented by AFSA and the product will be marketed and distributed via AFSA.

DECLARATION OF CONFLICT OF INTEREST
The author declares no conflict of interest.

This article has been peer reviewed.

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