Current Practice

Clinical utility of spirometry in pre-school children

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Introduction
Assessment of lung function using spirometry is crucial to the management of childhood lower respiratory tract disorders. The technical aspects for spirometry in pre-school children are more or less similar to that of older children and adults. However, when assessing young children, it is essential to have a well-trained technician and a child–friendly environment which has a significant impact on child's performance during the test. This article summarizes the basic sciences relevant to spirometry and the clinical use of spirometry in pre-school children.

What is spirometry?
Spirometry is a physiological lung function test that measures the volume and flow of air expired or inspired. In clinical practice, spirometry is useful to diagnose airway diseases, monitor disease progress and assess the effect of drug delivery[1,2]. After the spirometry technique was first established in adults, there was a debate whether the same technique could be applied to children. Very soon it was established that most children older than 6–8 years of age are capable of performing spirometry effectively with highly accurate test results[3,4]. However, spirometry in pre-school children has repeatedly shown high failure rates, especially when performing maximum expiratory flow volume (MEFV) manoeuvres, which was attributed to lack of coordination and poor attention in this age group[5]. Based on initial observations, the use of spirometry in pre-school children was restricted to 'partial' flow–volume manoeuvres[6]. However, more recent studies in pre-school children, using advanced user-friendly spirometry equipment currently available in the market, have confirmed that pre-school children have the ability to perform these manoeuvres effectively and accurately[7-9].

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What should you consider when performing spirometry?
For high quality test results, it is of utmost importance to have accurate equipment, technical expertise, good test procedures, appropriate reference values and quality control. However, when performing the test in young children, much attention should be paid to the following aspects: making environment child–friendly, gaining the trust of the child, giving detailed but simple instructions, allowing sufficient time for training and a lot of patience. It is important to keep the child under close observation to make sure that air does not leak and that the manoeuvre is correctly performed. Even if the child fails initially to perform the manoeuvres effectively, he/she may be successful in subsequent attempts with sufficient encouragement[10]. This requires a well-trained pulmonary function technician with adequate training and specific qualities of handling children[11].

As pre-school children show lack of coordination and poor attention, the use of computerized visual incentives can facilitate the MEFV manoeuvres though their use is not mandatory[12]. The fact that height and weight influence the accuracy of interpretation of lung function test results, makes it important to take anthropometric measurements accurately using a calibrated stadiometer and scales with correct technique in pre-school children who show rapid growth during early childhood[11]. It is essential to use disposable mouthpieces and bacterial filters while performing spirometry to prevent infection transmission between children[13].

What is forced expiratory manoeuvre?
The forced manoeuvre helps directly to measure forced expiratory volume at 1 second (FEV_1), forced vital capacity (FVC), peak expiratory flow rate (PEFR) and forced expiratory flow at 25-75% of forced vital capacity ($FEF_{25-75\%}$) and spirometry can display the flow volume curves during a forced manoeuvre. Optimally, correct performance of each

manoeuvre should be ensured prior to starting another manoeuvre.

During forced manoeuvre, spirometry could be done with the child in the sitting or standing position. Use of nose clips in pre-school children is not mandatory for acceptable recordings, but it should be recorded[14]. Even if the principle of the technique is the same as for adults and older children, the pre-school child should be trained to perform the forced manoeuvres in three distinct steps, namely the child should be able to: 1) take a deep breath to full inflation of lung, 2) blow out forcefully as fast as he can, and 3) continue blowing out forcefully till no more air can be expired or until 'the technician tells child to stop'[11]. A minimum of three manoeuvres should be recorded as in adults, but pre-school children may undertake 10 or more attempts without exhaustion until they achieve perfect technique and an acceptable spirometric recording[15].

What are the special considerations for acceptability and repeatability criteria?

While the principles of quality control of spirometry in pre-school and school-aged children are essentially the same as in adults, criteria for acceptable data in pre-school children need to be modified due to their small absolute lung volumes and big airway sizes relative to older children and adults. Therefore, forced expiration often ceases within one second in pre-school children so that it may be unreliable to use the recommended 6 second minimum forced expiratory time (FET) for adults[11,15] in young children. Similarly, in order to assess the repeatability, the use of percentage differences in volume (FVC) or flow (FEV_1) seem to be more appropriate than use of differences in absolute volumes (FVC) or flows in children.

To accept the spirometry recordings, they should show a good start, a good end with satisfactory exhalation time and meet reproducibility criteria.

1. ***Start-of-test criteria***
   Backward extrapolated volume (Vbe) is the parameter of choice to accept the good start of test. A recent study has shown that Vbe criteria for adults are inappropriate for the pre-school age group[15], and it should be less than 0.15 L for adults as recommended by the American Thoracic Society (ATS)[16]. Arets *et al.* evaluated the applicability of ATS and European Respiratory Society (ERS) criteria recommended for adults in respect of spirometry in children with a study of 446 school aged children. In their study, 94.5% of children aged <15 years were able to achieve Vbe <0.15 L criterion. Therefore they suggested using a minimum Vbe of 0.12 L in children less than 15 years old so that nine tenths of children could attain the acceptability standard[15].

2. ***End-of-test criteria***
   The forced expiratory time (FET) that the pre-school children can achieve during the forced expiration is an arbitrary point. By evaluating both ATS and ERS criteria, Arets *et al.* showed that 84.7% of children were able to reach maximum FET <6 seconds and therefore they suggested using 2 seconds for children 8 years of age or more and 1 second for children less than 8 years of age[17]. Desmond *et al.* observed that 7% of children under the age of 7 years achieved an FET of more than 6 seconds[18]. Kanengiser and Dozor performed spirometry tests for 98 children 3-5 years of age having respiratory disorders[3]. Ninety-five percent of them were able to achieve exhalation which lasted at least 1 second. Further studies have suggested taking 3 seconds[18] or 4 seconds[19] as cut-off times for exhalation.

3. ***Reproducibility criteria***
   Reproducibility can be evaluated either by the absolute difference between FVC and FEV_1 or by using the percentage difference between FVC and FEV_1 of the two best out of 3 or more curves per individual. While ATS criteria[16] recommend using the absolute difference between FVC or FEV1 for adults, ERS criteria recommend using the percentage difference between FVC and FEV_1 which should be less than 5%[20]. Aurora *et al.* found that current reproducibility criteria for adult spirometry are not appropriate for pre-school children[15]. Arets *et al.* observed that the percentage difference being independent of age and height would be more appropriate for use in children to assess reproducibility than absolute differences which is significantly affected by age and height. Therefore they suggested that the current 5% criteria as recommended by ERS would be more appropriate in children than the absolute criterion of either 100 or 200 ml[17]. Crenesse *et al.* observed that 55% (196/355) of pre-school children were able to demonstrate considerably two reliable manoeuvres which were reproducible with 0.1 L of FVC and FEV_1[21].

What is the utility of FEV1?

Though FEV1 is specifically used as an index to assess bronchial obstruction in older children and adults, its utility in pre-school children may not be reliable as they cannot forcefully exhale more than 1 second due to the presence of a small lung volume[22]. Recent studies have extended their effort to assess the utility of FEV at 0.5 second or FEV at 0.75 second as valuable determinants of airway obstruction in this age group[15,23]. Kanengiser and Dozor suggested that the use of $FEV_{0.5}$ could serve as a better outcome measure in interpretation of airway obstruction in pre-school children. Though the FEV_1/FVC ratio is considered a valuable indicator when assessing obstructive airway disease, pre-school children have reported ratios of FEV_1/FVC as high as 90 to 95%[2,7,24].

What is the value of the bronchodilator response (BDR)?

BDR usually assesses reversibility of airflow obstruction, aids diagnosis, and helps plan long-term bronchodilator therapy. Limited data are available on BDR in young children less than 8 years of age. BDR is commonly expressed in one of 3 ways viz. per cent of initial spirometric value, percent of predicted value and absolute change. However, in pre-school children, there is no clear consensus on the best method to express BDR[25-27]. A study in pre-school children has reported that the BDR in normal and asthmatic children may overlap so that it is difficult to define a cut-off value for a positive BDR in those patients[28]. Further, it will lead to over-diagnosis or under-diagnosis of asthma.

Spirometry in children is often dependent on the child's performance and the technician's skills because measurement of airway resistance through forced exhalation needs child's cooperation and attention. However, lung function tests such as whole-body plethysmography, interrupter technique and forced oscillation technique can measure the airway resistance in the respiratory passage with minimum cooperation of children as these tests can be performed with tidal breathing. The other key feature of most of these tests is non-invasiveness making it easy to apply in pre-school children. However, when selecting lung function tests, especially for the clinical set-up to diagnose airway disease and monitor their progression, it is important to consider the availability, cost, acceptability and repeatability criteria of various parameters measuring airway resistance.

In summary, spirometry is now feasible in pre-school children provided there is a well-trained technician with a child friendly environment which significantly impacts on the child's performance level. However, considering the growth and development of the respiratory system in young children, further studies are needed to standardize the acceptability and repeatability criteria for the quality control of spirometry in this age group.

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