PAEDIATRIC PULMONARY FUNCTION TESTS (PFT) - A Review.

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1. Md Al-Amin Mridha, 2. ARM Luthful Kabir, 3. Md Ruhul Amin

Pulmonary Function Tests (PFT) of various types are utilised clinically and epidemiologically to measure functional status in order to assess the pulmonary diseases[1]. It provides the objective criteria in diagnosis and management of asthma[2]. PFT in a child differs from that in adult largely because of the volume change that occurs from birth through the period of growth to the adulthood. These differences influence technique, methodology and interpretation[3,4]. Theoretically, ventilation, perfusion and diffusion of gases, dynamic lung volumes and capacities, lung compliance and elasticity, airway resistance and respiratory rate can be studied to assess pulmonary function[5].

The major clinical indication for performing pulmonary function tests are as follows [6]:

- To determine if symptoms and signs such as dyspnoea, cough and cyanosis are of respiratory origin
- To characterize pulmonary diseases physiologically. Although PFTs are not diagnostic for a specific pulmonary disorder, they may suggest disease etiology
- To monitor the course of lung function impairment
- To determine the effectiveness of therapy
- To anticipate the need for postoperative oxygen and/ or assisted ventilation. Preoperative pulmonary function evaluation is particularly important in patients with chest wall deformities e.g. scoliosis, collagen vascular diseases and neuromuscular diseases.

PULMONARY FUNCTION TESTING IN CHILDREN AND ADOLESCENTS

Ventilatory Lung Function Tests

Spirometry

Spirometry is indicated in all the children with diagnosis of asthma, chronic/recurrent cough or wheeze exercise induced cough or breathlessness and with recurrent respiratory manifestations. Spirometry can be reproducibly done from the age of 5 years but these values should be interpreted with individual considering age, sex, height and nutritional status[7].

Spirometry measures the volume of air exhaled from the lungs during a maximal expiratory manoeuvre. The forced vital capacity is the total volume of air that can be exhaled after a full inspiration. Though it is measured by spirometry, it is technically a volume and not a flow rate. Forced expiration is begun at TLC and ends at RV and usually takes less than 3 seconds. Forced expiratory volume in 1 second FEV_1) is the volume of air forcefully expired from full inflation in the first second. Both FVC and FEV_1 are recorded in litres. Healthy children are able to exhale >80% of their FVC in 1 second. There is a trend for the FEV_1/FVC ratio to decrease slightly after early adulthood. Any spirometer must calculate or display the FVC, FEV_1, and PEFR. Healthy children and adolescents aged 6 years to 16 years perform pulmonary function studies as reproducibly as healthy adults [8]. (figure 1)

Interpretation of spirometry: Spirometry not only allows the characterization of a patients lung function against reference values but also defines the disease class. Most lung diseases can be classified as obstructive, restrictive or mixed- type processes. The configuration of the flow-volume and volume-time curves when taken from a maximal forced expiration can provide valuable information about the disease class when compared with the normal curve. In obstructive diseases, flow decreases rapidly as gas exhaled giving a flow volume curve hich is convex towards the volume axis. In restrictive disease, the curve shape is normal but smaller than the normal curve. (figure 2)

Spirometric data interpretation should include an assessment of the quality of the study. The following criteria have been laid down for an acceptable test:

(a) Appropriate curve shape which is artefact free

(b) Sustained expiration for at least 3 seconds

(c) At least 3 forced vital capacities within 10% of the best effort and

(d) Satisfactory effort by the patient as observed by the tester.(table-I)

Peak Expiratory Flow Rate

Peak expiratory flow rate (PEFR) is the maximal expiratory flow rate sustained by a subject for at least 10milliseconds expressed in Litre per minute (L/min) [9]. PEFR had been used as measurement of ventilatory capacity by simplified device the mini-Wright peak flow meter[10].

Indications:

- To assess and to diagnose reversible air way diseases
- To predict the impending ventilatory failure, such as Guillain-Barre syndrome, Paralytic polio etc.

Clinical interpretation of values of PEFR:

Personal based value of PEFR can be compared to normal reference population and also with predicted value. PEFR records with diurnal variation of 20% or more is a good clinical and occupational indicator of asthma [11]. Predicted PEFR values, of Bangladeshi boys and girls, can be found out easily by the following formula- boys PFER (l/min) =5.96×Ht (cm) – 495 and girls PEFR (l/min) =5.70×Ht (cm) – 479 as well as by nomogram (Figure 3 and figure 4)[12].

PEFR variability- diurnal variation in peak flow rate expressed as the formula as follows [13]-

$$Daily\ variability\ = \frac{HighestPEFR - LowestPEFR}{HighestPEFR} \times 100$$

Bronchial provocation test by exercise in 'exercise induced asthma' is diagnostic when PEFR falls 15% of personal based after exercise and reversibility of airway obstruction is evidenced by an increased in PEFR more than 20% after an adequate dose of nebulized bronchodilator is diagnostic for asthma [14] but bronchial reversibility of an increased at least 10% in PEFR after aerosol therapy is strongly suggestive of asthma [15]. Self management of bronchial asthma is advised to maintain a peak flow chart and personal based result should be interpreted in following ways-

Green zone (Safe zone) - 80-100% of personal best result

Yellow zone (Zone of alert)- <80%->50% of personal best result

Red zone (Zone of emergency)- <50% of personal best result [16]. PEFR can be used as a guideline of admission and discharge of asthma when:

PEFR value >60% of expected- admission probably unnecessary

40-60% of expected- consider admission

<40% of expected- admission probably necessary [17]

Serial measurement of PEFR in or progressive flaccid paralysis to predict the involvement of respiratory muscle is clinical important to give warning of the hypoventilation and need for ventilatory support[18].

Body plethysmography, Gas (helium) dilution and Eosophageal pressure technique

Direct measurement of lung volume (TLC, FRC and RV) and air way resistance (R_{aw}) were measured. Body plethysmography is preferable both for procedural and technical reasons but the instrument may not be available everywhere. With the rapid electrically activated mouth shutter used in plethysmography, it is possible to obtain the measurement of thoracic gas volume (TGV) which is the same as FRC.

Airway resistance (R_{aw}) in older children is usually assessed using the body plethysmograph. Resistance is usually converted to its reciprocal, airway conductance (G_{aw}) because this value

is linearly related to lung volume. Conductance can then be normalized for increases in lung volume with growth by dividing it by FRC (specific airway conductance, SG_{aw}).

Gas dilution method is simple. A known concentration of gas (usually helium which is nonabsorbable, inert) is breathed in a closed circuit and allowed to equilibrate with as already in the lung. FRC or RV are calculated from measuring gas [19].

Total lung volume, even in infant is accurately measured by oesophageal pressure technique in which balloon contain catheter placed in the lower third of the oesophagus, balloon is inflated by 0.3-0.5 ml air, or fluid then with help of plethysmographic pressure changes total volume is calculated[21].

Assessment of Pulmonary Gas Exchange or Diffusion

Blood gas analysis

Arterial blood gas analysis provides the most sensitive index of lung function [oxygen (O_2) uptake and alveolar ventilation] in infants and children. Arterial samples must be collected free of air bubbles and analyzed as soon as possible, preferably within 15 minutes. Polypropylene syringes are acceptable for transport or storage of the specimen. In small infants in whom frequent arterial samples are required, sample size may be no greater than 0.5 ml. In older children a larger sample size should be obtained. The radial is the most accessible superficial arteries in newborn infants and in children. The Allen test to determine ulnar artery patency should be performed prior to radial artery puncture. Temporal artery puncture should be avoided and placement of an indwelling temporal artery catheter has been associated with focal brain necrosis[22]. Various parameters of arterial blood gas analysis of a normal individual should be in the range of pH 7.35 to 7.45, $PaCO_2$ 35 to 45mmHg (>50mmHg indicate hypercapnia), PaO_2 85 to 105mmHg (<60mmHg indicate hypoxia),

HCO_3 21 to 28mmol/L, TCO_3 20 to 28mmol/L, O_2 saturation >94% (O_2 saturation <85% clinically appears cyanosis) and BE ±2mmol/L in a situation of normal barometric pressure.

Interpretation blood gas:

Step 1: Determination of acidemia (pH -7.35) or alkalemia(pH-7.45).

Step 2: Acidemia may be metabolic (decreased HCO_3^- level in blood) or respiratory (increased $PaCO_2$ level in blood) and alkalemia may be metabolic (increased HCO_3^- level in blood) or respiratory (decreased $PaCO_2$ level in blood).

Step 3: Metabolic acidosis may be *simple*, when $PaCO_2$ remain to be expected level (table-II); *mixed* metabolic acidosis and respiratory alkalosis, when $PaCO_2$ level remain to be lower than expected value or *mixed* metabolic acidosis and respiratiory acidosis than expected value after compensation.

Respiratory acidosis may be *simple*, when HCO_3^- remain to be expected level (table-II); *mixed* metabolic acidosis and respiratory acidosis, when HCO_3^- level remain to be lower than expected value or *mixed* respiratory acidosis and metabolic alkalosis, when HCO_3^- level remain to be higher than expected value after compensation.

Metabolic alkalosis may be *simple*, when $PaCO_2$ remain to be expected level (table-II); *mixed* metabolic alkalosis and respiratory alkalosis, when $PaCO_2$ level remain to be lower than expected value or *mixed* respiratory acidosis and metabolic alkalosis, when $PaCO_2$ level remain to be higher than expected value after compensation.

Respiratory alkalosis may be *simple*, when HCO_3^- remain to be expected level (table-II); *mixed* metabolic acidosis and respiratory alkalosis, when HCO_3^- level remain to be lower than expected value or *mixed* respiratory alkalosis and metabolic alkalosis, when HCO_3^- level remain to be higher than expected value after compensation[23].

Pulse oximetry

Noninvasive means of measuring oxygen saturation of haemoglobin. It exploits the light absorbency properties of haemoglobin. Deoxygenated blood absorbs more light in the red spectrum. Oxygenated blood absorbs more infrared light. The pulse oximeter measures the visible and infrared absorbencies and calculates the oxygen saturation. The light source and sensor of the oximetry probe must be placed directly opposite each other in an accessible place (e.g. nail-bed of the finger or toe, ear lobe). To know if the reading is reliable, the pulse rate recorded on the pulse meter must reflect the true pulse of the patient- hence the term *"pulse-oximeter"*. However, the accuracy depends on adequate perfusion. Its utility may be limited in patients with significant vasoconstriction and poor peripheral perfusion.

Indications for pulse oximetry: Any condition for which a patient may require supplemental O_2. Any patient with tachypnoea, all pneumonia patients, patients with wheezing, any patient with respiratory distress, any pulmonary operations or procedures[24]. The oxygen saturation level should be ≥94% in normal healthy persons.

Measurement of diffusing capacity

The carbon monoxide method (DL_{co}): A small amount of CO is breathed into the alveoli and the partial pressure of the CO in the alveoli is measured from appropriate alveolar air samples. Then, by measuring the volume of CO absorbed in a period of time and dividing this by the alveolar carbon monoxide partial pressure, one can determine accurately the CO diffusing capacity. To convert CO diffusing capacity to O_2 diffusing capacity, the value is multiplied by a factor of 1.23 because diffusion coefficient for oxygen is 1.23 times that for CO. Thus for average diffusing capacity for CO in young man 17 ml/min/mm Hg and that for O_2 is 21 ml/min/mm Hg [25].

Assessment of Pulmonary Perfusion [26]

Methods of measurement of pulmonary circulation: Assessment of circulatory function in the pulmonary vasculature depends on measuring pulmonary vascular pressures and cardiac output. With a flow directed pulmonary artery (Swan-Ganz) catheter, pulmonary arterial and pulmonary capillary wedge pressures can be measured directly, and cardiac output can be obtained by the thermodilution method. Pulmonary vascular resistance can be calculated according to the equation-

$$PVR = 80(PAP-PCW)/CO$$

Where, PVR= Pulmonary vascular resistance (dyne's/cm^5). PAP=Mean pulmonary artery pressure (mm Hg, 15 mm Hg). PCW= Pulmonary capillary wedge pressure (mm Hg). CO= Cardiac output (L/min).

The normal value for pulmonary vascular resistance is approximately 50-150 dynes/cm^5.

Ventilation-Perfusion by Lung Scan

Various techniques exist to demonstrate uneven pulmonary ventilation and perfusion, by measuring the alveolar-arteriolar difference for O_2, CO_2 , or for inert gases such as He or N_2. Radionucleotide lung scan technique using radioactive krypton, xenon, CO_2 and macroaggregates of radioactive human serum albumin with ^{99m}Tc are also available to study ventilation and perfusion. The distribution of radioactivity proportional to the pulmonary capillary blood flow is useful in evaluating pulmonary embolism, congenital cardio vascular and pulmonary defect[27].

PULMONARY FUNCTION TESTING IN INFANTS AND YOUNG CHILDREN

Pulmonary function tests in infants and young children are difficult due to technique and their absolute values rapid change with somatic growth still most of the lung function can be

evaluated. The consistent finding of tidal volume per kilogram body weight in infant is 7 to 9 ml/kg, can be measured by placing a tightly fitting mask over the nose and mouth attached to a pneumotachograph. The measurement of lung volumes in even newborns is done by body plethysmography and nasal pneumotachography (because infant less than 6 months old are obligate nasal breathers). Air way resistance and specific airway conductance can also be measured in infants using a body plethysmograph. Partial expiratory flow-volume (PEFV) by the rapid compression (thoraco-abdominal) technique, a relatively new method of lung function testing in infancy and young children which is performed instead of maximal forced expiratory flow method in adult. Blood gas analysis provides the most sensitive index of lung function in infants and children[19, 28, 29] .

Paediatric pneumogram

Quantification of ventilatory pattern during sleep is useful in diagnosis of respiratory control disorders specially in infants with apnoea. In this group all apnoea longer 15 seconds are abnormal. Heart rate below 80 up to 3 months, below 70 for 3-6 months, and below 60 over 6 month of age, are abnormal if sustained for 10 seconds. Any apnoea with bradycardia or, cyanosis is abnormal. Periodic breathing should not exceed 4% of total sleep time, except in preterm infants [30].

REFERENCE VALUES OF PULMONARY FUCTION TESTS

Lung volumes and flow rates vary with age, sex and ethnic group. In children it is particularly important to have age and sex matched reference values from a control population. When a patient's performance is evaluated against reference values from a similar population, it is called *referenced testing*. A patient's performance when tested against his or her own past performance is referred to as *longitudinal testing*. This is particularly valuable when observing a positive response to treatment or confirming progression of disease[28,31].

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Table I: Obstructive versus restrictive lung disease

	Obstructive	**Restrictive**
Spirometry		
FVC	Normal or reduced	Reduce
FEV_1	Reduced	Reduced
FEV_1/FVC	Reduced	Normal
FEF_{25-75}	Reduced	Normal or reduced
PEFR	Normal or reduced	Normal or reduced
Lung volumes		
TLC	Normal or increased	Reduced
RV	Increased	Reduced
RV/TLC	Increased	Unchanged
FRC	Increased	Reduced

FEV_1: Forced Expiratory Volume in one second, FVC : Forced Vital Capacity
FEF: Force expiratory flow, PEFR: Peak expiratory flow rate, RV: Residual Volume, TLC: Total Lung Capacity, FRC: Functional residual capacity

Table II: Appropriate compensation during simple acid-base disorders.

	Disorder	Expected compensation
1	Metabolic acidosis	PCO_2 =1.5 5[HCO_3^-] + 8±2.
2	Metabolic alkalosis	PCO_2 increasing 7 mmHg for each 10 mEq/L incease in the serum [HCO_3^-].
3	Respiratory acidosis Acute Chronic	 [HCO_3^-] increases by 1 for each 10 mmHg increase in the PCO_2. [HCO_3^-] increases by 3.5 for each 10 mmHg increase in the PCO_2.
4	Respiratory alkalosis Acute Chronic	 [HCO_3^-] falls by 2 for each 10 mmHg decrease in the PCO_2. [HCO_3^-] falls by 4 for each 10 mmHg decrease in the PCO_2.

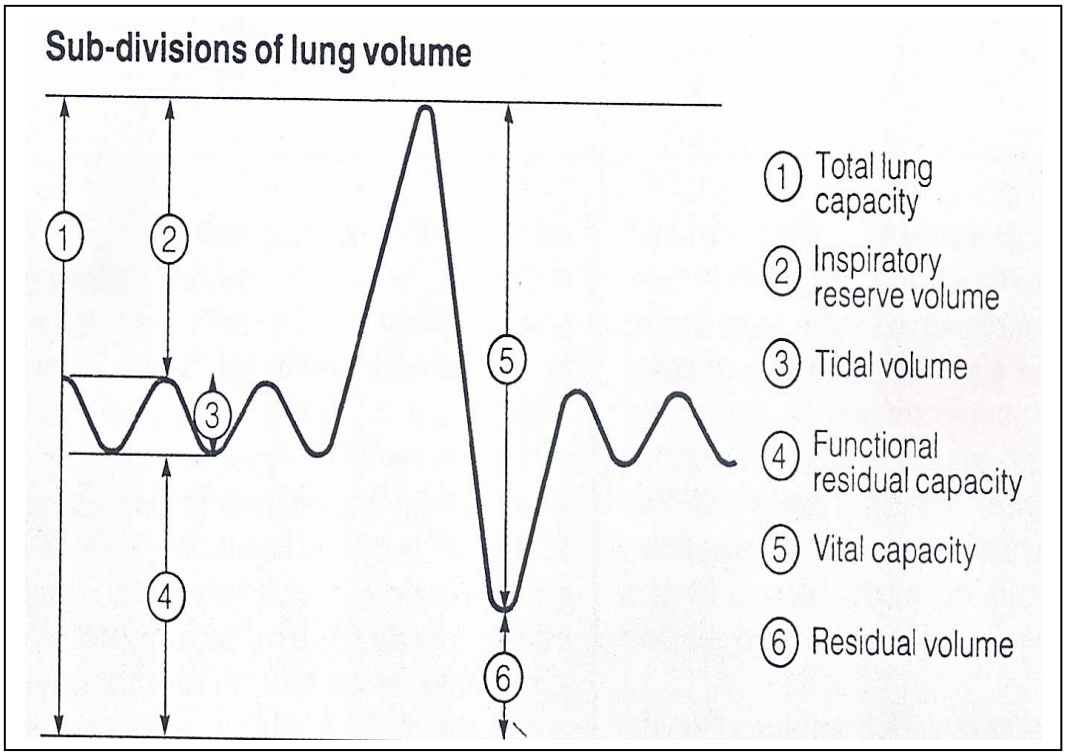

Figure-1: Sub-divisions of lung volume and capacity.

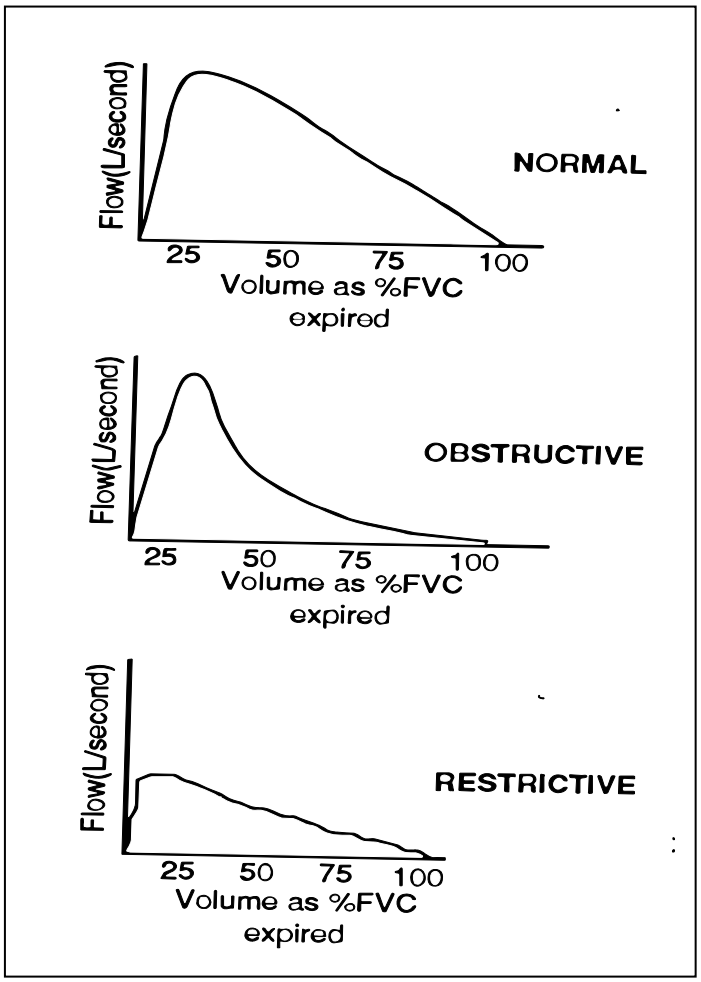

Figure-2: Comparison of flow-volume in normal versus disease states

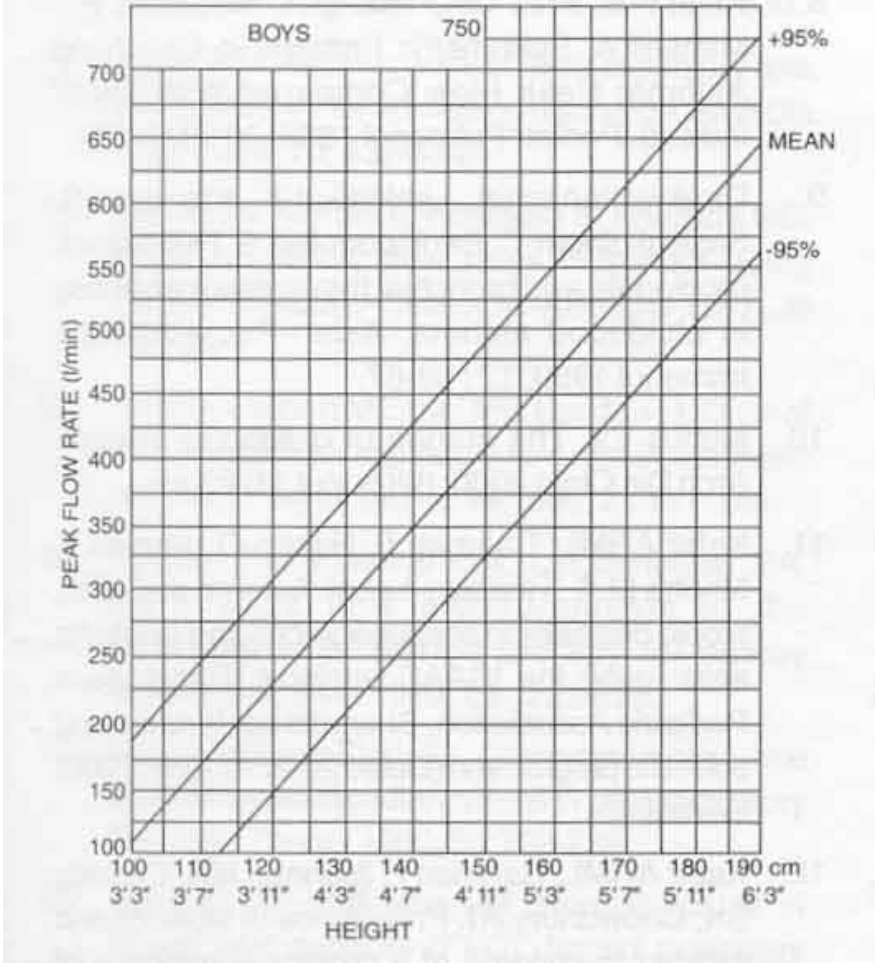

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Figure 3: Nomogram of normal PEFR (l/min) in relation to height (Bangladeshi boys)

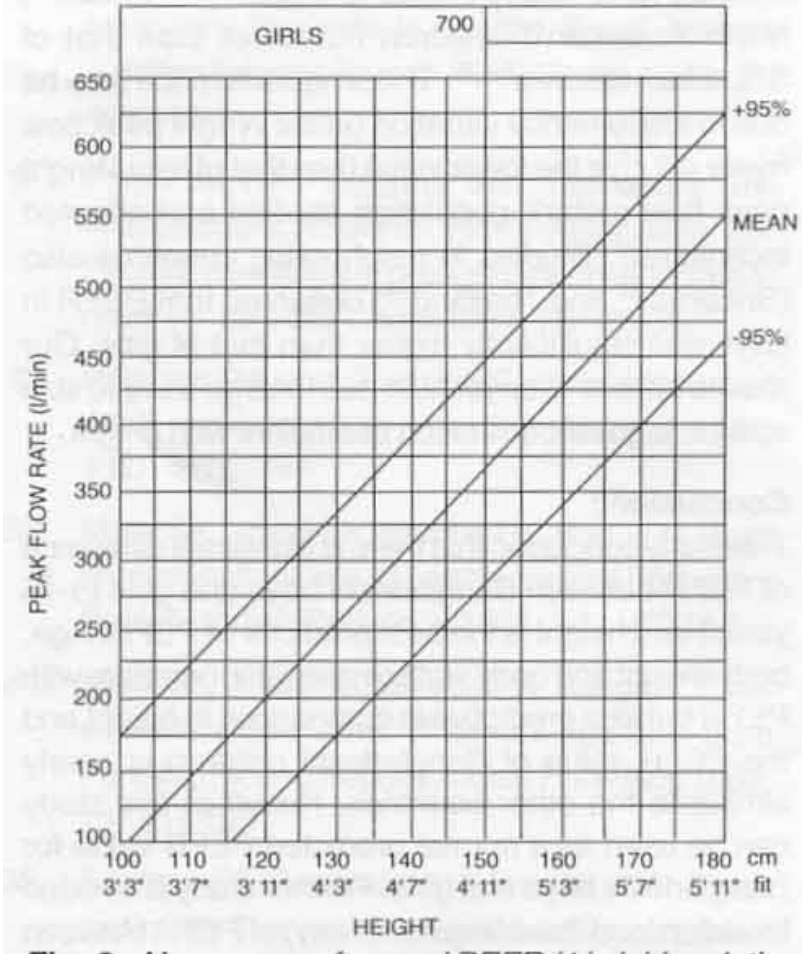

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Figure 4: Nomogram of normal PEFR (l/min) in relation to height (Bangladeshi girls)