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# PULMONARY FUNCTION TESTS (PFT's) IN NEWBORNS AND INFANTS

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In the past two decades there has been the substantial increase in interest in studying the respiratory function in newborns and infants. This interest has been caused by an increasing understanding of the importance of respiratory illness as a cause of childhood morbidity and mortality, and of the relationship between early life events and adult health.

Many PFT techniques used in co-operative patients, as whole body plethysmography and forced expiratory flow analysis have been adopted to newborns and infants. The other techniques as passive respiratory mechanics have been developed as noninvasive method to be used in neonates and infants.

**Preparation**

Regardless of which tests are to be performed, the preparation of the infant for PTF's is very similar. The clothing should not restrict respiratory movements, for most purposes PFT's should not be made within three weeks of an upper respiratory tract infection, measurement of body weight and length should be routine for every infant undergoing PFT. Tests tend to be more successful if the infant is fed. Most term and preterm neonates can be studied during natural sleep following a feeding. Beyond one month of age, however, it becomes increasingly difficult to perform any PFT, without sedation. The most commonly used sedative agent for PTF's is chloral hydrate. A single dose of it is 30—50 mg/kg, and in case of longer lasting PFT's (bronchial challenge) the dose may be increased up to 100 mg/kg. Nevertheless, it has to be remembered that in wheezy infants the dose of 70—100 mg/kg may cause a fall in arterial oxygen saturation and a decrease in clinical score. Chloral hydrate has been shown to reduce the activity of upper airway muscles [1], a factor that may predispose the airway to collapse during sedation. This concerns infants with craniofacial deformities, enlarged tonsils and/or adenoids, and known to have obstructive sleep apnea. Thus clinical assessment of the infant prior to sedation should include evaluation of any history of airway obstruction during sleep and visual assessment of the upper airway. Although complications following sedation are rare, upper airway problems, which may be undiagnosed prior to PFT's emphasize the need for continual monitoring and availability of resuscitation equipment during all PFT's.

Fully informed, parental consent or assent should be obtained for any PFT on an infant due to the sedation need.

**Whole Body Plethysmography**

Constant-volume plethysmographs are used primarily for the determination of functional residual capacity ($FRC_{pleth}$) or assessment of airway resistance ($R_{aw}$). The technique was first described by DuBois [2, 3] and was later adopted for use in infants [4, 5]. In practice, the baby lies inside the rigid, closed container and breathes through a pneumotachograph, which records tidal flow and, by integration, volume (Figure 1). When the airway opening is briefly occluded at the end of expiration to hold the lung at a constant volume, the infant makes respiratory efforts that compress and decompress the thoracic gas volume. By relating the resultant changes in alveolar pressure (measured at mouth level) to changes in alveolar volume (measured as plethysmographic pressure changes), thoracic gas volume at the moment of occlusion or functional residual capacity, can be calculated. In BTPS conditions changes in plethysmographic pressure during spontaneous breathing is inversely proportional to changes in alveolar pressure. Thus by relating changes in alveolar pressure to simultaneous changes in flow at the airway opening, the airways resistance can be calculated.

The indications for plethysmography in infants may be as follows [6]:

- to understand better the pathophysiology in various conditions:
- cystic fibrosis (CF), wheezing illnesses, bronchopulmonary dysplasia (BPD), gastroesophageal reflux, cardiovascular diseases
- to study the growth and development of the lungs following premature delivery and/or ventilatory support during the neonatal period
- to evaluate efficacy of therapeutic interventions
- to assess bronchial hyperreactivity

A large number of publications have reported the predicted values of FRCpleth in infants. In such studies lung volume has frequently been expressed per kilogram of body weight. Using this approach, there has been agreement in the past that mean FRCpleth in neonates is approximately

32 mL/kg. The reference values of FRCpleth in infants published according to different authors are shown in Table 1.

There is relatively few publications on the reference values of Raw in infants (Table 2).

**Forced expiratory flow analysis**

There are two ways to achieve "forced" expiration in infancy. One is to use externally applied thoracoabdominal pressure — rapid thoracic compression (RTC). The other one is to use negative pressure via a tracheal tube — forced deflation technique (FD). RTC technique was first used in infants almost thirty years ago [11] and was modified by adding the inflatable jacket [12, 13] (Figure 2). The jacket encircles the chest and abdomen and is used to force expiration from the end of an inspiration during tidal breathing. Therefore this maneuver is considered as a partial forced expiratory flow and the parameter most used is the maximal flow at functional residual capacity ($V'_{max\ FRC}$)(14) (Figure 3).

This parameter has been used to:

- determine normal physiological growth and development of the infant respiratory system
- assess abnormalities of lung function in infants with recurrent wheeze, CF, BPD
- evaluate the efficacy of treatment regimes including inhaled bronchodilators
- assess bronchial responsiveness in healthy and wheezy infants
- determine the influence of various factors (respiratory tract infection, gender, maternal smoking, atopic family history) on infant pulmonary mechanics.

The major disadvantage of the technique is the lack of a reliable volume landmark. The $V'_{max\ FRC}$ measurement relies on FRC which is unstable in infants and depends on the airway caliber and sleep state [15].

FD technique with a negative pressure applied to the airways opening in human infants was first described by Motoyama [16]. The lungs are inflated up to TLC and then a constant negative pressure is applied. The lungs are deflated until expiratory flow ceases at RV level. FD was used in pre-term and full-term infants with normal lung function and in infants with various pulmonary diseases including BPD [17], viral bronchiolitis [18], congenital diaphragmatic hernia [19], meconium aspiration syndrome [20]. In many of these reports FD technique was also used to evaluate airway response to bronchodilators. The main advantage of this technique is the ability to obtain full and reproducible MEFV curves allowing to measure FVC and maximal expiratory flows at 5% and 10% FVC ($MEF_{25}$ and $MEF_{10}$) [21]. The main disadvantage of the technique is its limitation to use in subjects having a tracheal tube or tracheostomy cannula placed. The subject must be deeply sedated or anesthetized.

**Passive respiratory mechanics**

The measurement of passive respiratory mechanics depends on the absence of respiratory muscle activity. If an infant's airway

*Table 1*

**$FRC_{pleth}$ reference values in the first two years of life (Caucasians )**

| Author — Year | Age [weeks] | $FRC_{pleth}$ [ml * $kg^{-1}$] |
|---|---|---|
| Gutkowski — 1986 (7) | 24–96 | 30,1 |
| Lindemann — 1982 (8) | 2–104 | 33,5 |
| Milner — 1978 (9) | 0,01–0,9 | 33,4 |

*Table 2*

**$R_{aw}$ [kPa*$L^{-1}$*s] reference values in the first two years of life (Caucasians)**

| Author, Year | Number | Age [weeks] | Regression Equation | r |
|---|---|---|---|---|
| Gutkowski, 1986 (7) | 50 | 24–96 | 4,41–0,034 * L | –0,72 |
| Lindemann, 1982 (8) | 153 | 2–104 | 3,47–0,028 * L | –0,47 |

L — body length [cm]

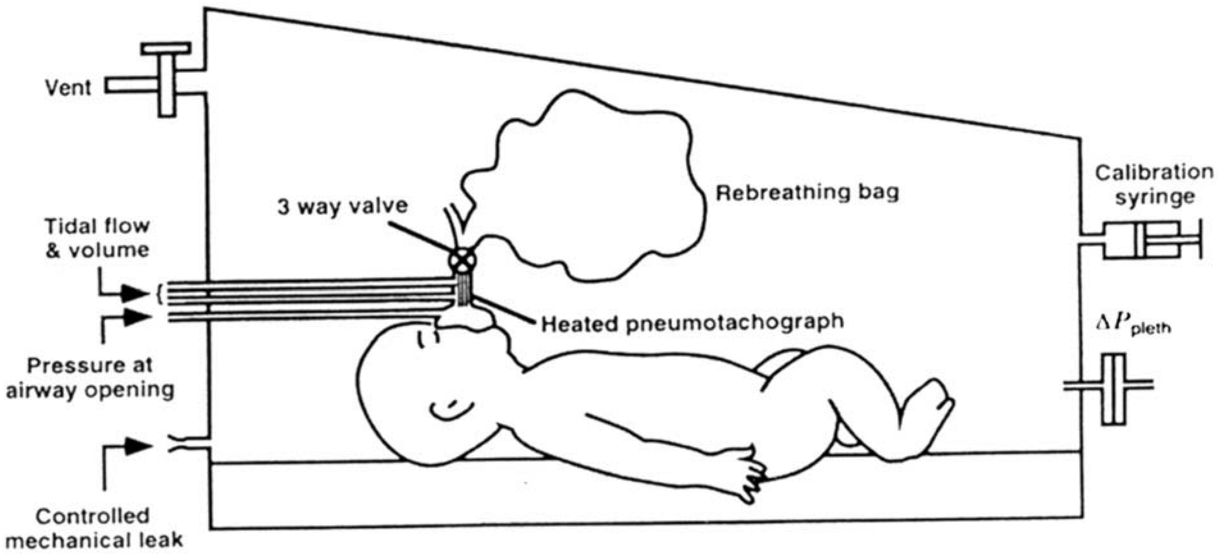


*Figure 1: Schematic diagram of an infant whole body plethysmograph. Gas compression and expansion within the plethysmograph during the respiratory cycle are measured by a pressure transducer [6].*

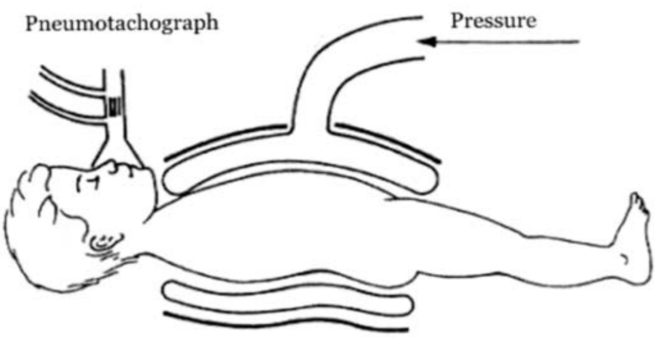


*Figure 2: The rapid thoracoabdominal compression technique of measuring partial expiratory flow-volume curves. The inflatable jacket is connected to a pressure reservoir, the pneumotachograph measures flow [15].*

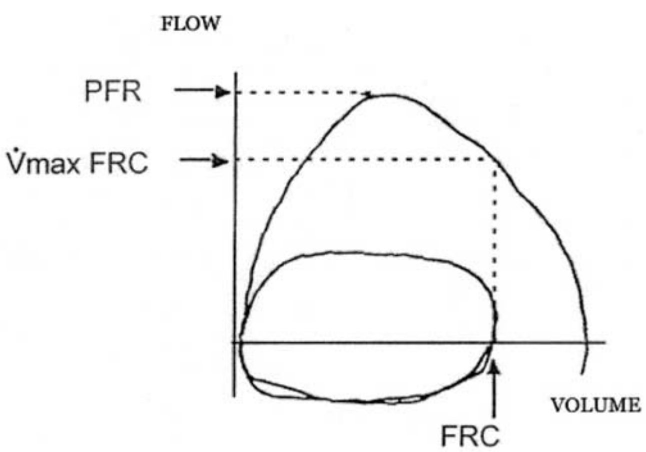


*Figure 3: An example of a tidal volume partial expiratory flow-volume curve showing the derivation of maximal flow at functional residual capacity [15].*

is briefly occluded at end-inspiration, the Hering-Breuer inflation reflex (HBIR) may be induced to relax the respiratory muscles [22]. This forms the basis of two occlusion techniques, single breathe technique (SBT) and multiple occlusion technique (MOT), both assume complete relaxation of the respiratory muscles and equilibration of pressure throughout the airways during occlusion reflects the elastic recoil pressure of the respiratory system and a relaxed airway pressure may be recorded (Figure 4A).

SBT aims to induce relaxation of the respiratory system both during and after end-inspiratory airway occlusions. This allows measurement of the elastic recoil pressure at the airway opening, during relaxation against shutter, and calculation of respiratory system compliance ($C_{rs}$), respiratory system resistance ($R_{rs}$) and respiratory system time constant ($\tau_{rs}$) from the passive flow-volume curve during relaxed expiration (Figure 4B). The objective of the MOT is to perform a series of brief airway occlusions, over the first two-thirds of expiration, during which the respiratory muscles relax and airway pressure equilibrates, so that a volume-pressure slope for the relaxed respiratory system can be constructed (Figure 5). Analysis of $C_{rs}$ from the multiple occlusion technique is based on the relationship between the volume above FRC at the moment of occlusion and the elastic recoil pressure measured during that occlusion.

Techniques for assessing passive respiratory mechanics are simple to use, noninvasive, and well tolerated by most infants. Under passive conditions $C_{rs}$ values obtained from SBT and MOT do not show significant differences [23]. Passive mechanics measurements have been used to evaluate the short- and long-term pulmonary outcome of infants treated with surfactant at birth and of infants with bronchopulmonary dysplasia [24, 25]. Crs values well clinically characterize the newborns with respiratory distress syndrome [26].

It is now possible to perform a variety of measurements of respiratory mechanics in infants. These have already proved valuable in revealing the normal functional development of the lungs and in predicting and tracking infant respiratory disease and responses to therapy.

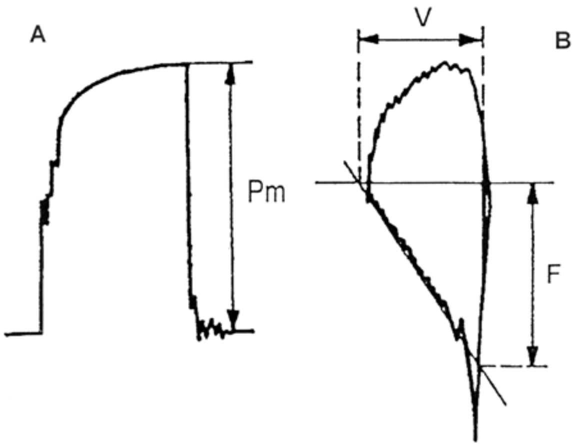


*Figure 4 A: SBT — An example of a mouth pressure plateau showing the relaxation of respiratory muscles and reflecting an elastic recoil pressure.*
*Figure 4B: SBT — Passive flow-volume loop following the release of occlusion. The straight line is extrapolated to to the flow and volume axis. The resistance and compliance of the respiratory system ($R_{rs}$ and $C_{rs}$ respectively) are calculated by the following equations: $R_{rs} = P_m/F$; $C_{rs} = V/P_m$. The time constant ($\tau_{rs}$) is the slope of the straight line and $\tau_{rs} = R_{rs} \times C_{rs} = V/F$ [27]*

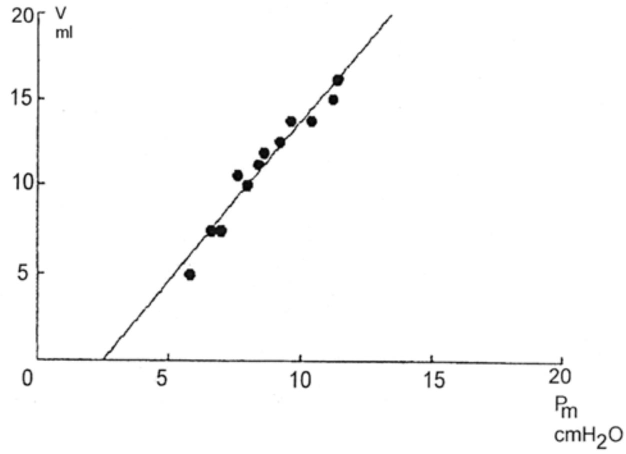


*Figure 5: MOT — volume-pressure plot. Crs is the slope of the regression line: V/Pm [27].*

As with older children and adults, the clinical management of infant s with lung diseases such as asthma, bronchopulmonary dysplasia, cystic fibrosis and congenital cardiorespiratory disease may benefit from objective assessments of pulmonary function.

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## ТЕСТЫ ЛЕГОЧНОЙ ФУНКЦИИ (ТЛФ) У НОВОРОЖДЕННЫХ И МЛАДЕНЦЕВ

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*Резюме*

Значительно возросло понимание роли респираторных нарушений (заболевания) как причины детской заболеваемос-

ти и смертности, а также взаимозависимости между событиями, имеющими место на ранних стадиях жизни, и здоровьем в зрелости. Это и послужило основанием нашего желания провести тщательный анализ повышенного интереса к респираторной функции у новорожденных и младенцев, наблюдаемого в последнее время.

Поэтому при выполнении настоящей работы было решено сосредоточить внимание на методологии выполнения тестов легочной функции у данной возрастной группы лиц. Была проведена подготовка младенцев к выполнению ТЛФ независимо от метода и условий измерения, необходимости письменного согласия родителей и используемых седативных препаратов.

Использовались основные методы, среди них: плетизмография всего организма, анализ форсированного выдоха в двух вариантах (метод быстрой компрессии легких и метод форсированной дефляции), а также пассивной респираторной методики, определяемая с помощью одноразового вдоха и методом множественной окклюзии. Каждый из этих методов кратко описан, его принцип объяснен, показания, преимущества и недостатки обсуждаются. В случае плетизмографии целого организма в работе приводятся предсказуемые величины функциональной остаточной емкости и сопротивления воздухоносных путей согласно различным авторам.

В устном сообщении на Симпозиуме будут представлены практические применения вышеописанных методов. В свете показаний для выполнения функциональной диагностики у детей младших возрастных групп, будут обсуждаться следующие вопросы: (а) связь между свистящим дыханием и гиперактивностью воздухоносных путей у младенцев; (б) роль гастро-эзофагального рефлюкса у младенцев в гиперчувствительности их воздухоносных путей; (в) корреляция между показателями респираторной системы у новорожденных, страдающих бронхолегочной дисплазией, и их потребностью в кислороде и респираторной поддержке.