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Mini-symposium: Chest Wall Disease

Options for Assessing and Measuring Chest Wall Motion

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EDUCATIONAL AIMS

The reader will be able to:

- Understand the reasons for and importance of measuring chest wall motion
- Have a basic grasp of the physiology of chest wall motion during respiration
- Be acquainted with a wide range of methods used for assessing chest wall motion
- Be aware of the main advantages and disadvantages of each method
- Understand how tidal flow and thoraco-abdominal asynchrony markers are derived

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SUMMARY

Assessing chest wall motion is a basic and vital component in managing the child with respiratory problems, whether these are due to pathology in the lungs, airways, chest wall or muscles. Since the 1960s, clinical assessment has been supplemented with an ever-growing range of technological options for measuring chest wall motion, each with unique advantages and disadvantages. Measurements of chest wall motion can be used to: (1) Assess respiratory airflow and volume change, as a non-invasive alternative to measurement at the airway opening, (2) Monitor breathing over long periods of time, to identify apnoea and other types of sleep-disordered breathing, (3)Identify and quantify patterns of abnormal chest wall movement, whether between ribcage and abdominal components (thoracoabdominal asynchrony) or between different regions of the ribcage (eg in scoliosis and pectus excavatum). Measuring chest wall motion allows us to do things which simply cannot be done by more mainstream respiratory function techniques measuring flow at the airway opening: it allows respiratory airflow to be measured when it would otherwise be impossible, and it tells us how the different parts of the chest wall (eg ribcage vs abdomen, right vs left) are moving in order to generate that airflow. The basis of the different techniques available to assess and measure chest wall motion will be reviewed and compared, and their relevance to paediatric respiratory practice assessed.

WHY MEASURE CHEST WALL MOTION?

For the purposes of respiration (and of this article), the chest wall is defined as all of the structures on the outside of the body which surround the lungs and which move as the lungs fill and empty - this includes both the thoracic wall (ribcage) and the abdominal wall [1]. Assessing chest wall movement has been attempted for as long as doctors have been examining patients. We were all taught at medical school to try to assess chest expansion by placing our hands on the chest with thumbs in the midline (“thumb excursion test” [2]); more usefully, paediatricians have long employed visual Gestalt assessment of thoraco-abdominal asynchrony (“recession”) as a marker of acute respiratory disease. But as Kelvin observed: “when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind.. you have scarcely, in your thoughts, advanced to the stage of science.” [3]. Quantifying chest wall movement has been attempted for a number of overlapping reasons, including:

- to measure tidal volume and respiratory airflow pattern - eg time to peak tidal expiratory flow over total expiratory time (t_{PTEF}/t_E) - in situations where measurement at the airway opening is

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impossible or poorly tolerated (eg the young, uncooperative child [4], acute respiratory disease [5,6]; non-invasive ventilation [7–9]; ambulatory exercise [10,11])

- to monitor breathing and identify central and obstructive apnoeas over long periods of time [12] (eg neonatal care, during sleep)
- to quantify the degree of asynchrony between chest and abdominal respiratory motion (thoraco-abdominal asynchrony - TAA) as a measure of upper or lower airway obstruction (eg croup [6], cystic fibrosis [13], wheezing disorders [14] and bronchopulmonary dysplasia [15])
- to characterise patterns of pathological chest wall movement in chest wall or neuromuscular disease (eg pectus excavatum [16,17], scoliosis [18], spinal muscular atrophy [19], Duchenne muscular dystrophy [20], osteogenesis imperfecta [21], prune belly syndrome [22])
- to assess changes in end-expiratory lung volume (eg in ventilated infants [23])

PHYSIOLOGY OF CHEST WALL MOTION

Just prior to the start of inspiration, efferent impulses from the respiratory centres in the brain travel to the muscles of the pharynx (to stiffen that muscular tube), the intercostal muscles (to stiffen and expand the ribcage) and the diaphragm. This normally results in both (i) generation of negative pleural and hence alveolar pressure and (ii) a patent airway, causing a tidal volume (V_T) of air to enter the lungs with concurrent expansion of both the ribcage (RC) and abdominal (AB) components of the chest wall. In practice, there is often a very slight lag between AB expansion and RC expansion [24]. In physiological situations (eg rapid eye movement sleep) and disease, in which there is obstruction to airflow and/or inadequate stiffness of the ribcage, this lag is increased [25,26]; in more extreme situations there may even be inward RC movement at the same time as outward AB movement ("paradoxical" respiration). RC expansion is not necessarily uniform, and especially in young infants and in chest wall disease (eg osteogenesis imperfecta), some ribcage areas may move outwards while others move inwards.

Konno and Mead [1] were the first to attempt the measurement and mathematical analysis of chest wall motion. Using ingenious equipment which could have appeared in a W. Heath Robinson print (strings on pulleys attached to the chest and abdominal wall by squashed ping-pong balls, whose movement was measured by linear transducers - Figure 1), they demonstrated that it was possible to predict volume changes (measured by spirometer) reasonably accurately in healthy adult subjects by measuring changes in the AP diameter of RC and AB. They also showed that the relative contribution of RC and AB to volume changes varied widely under different conditions: for example, AB excursion contributed well over half of tidal volume, but much less than half of vital capacity; and AB contributes more to volume change in supine than standing.

METHODS FOR MEASURING CHEST WALL MOTION

Since Konno and Mead's seminal article, a wide variety of measurement methods have been employed, and can be classified as follows:

1. Methods using physical devices placed on the chest wall
   a) Measuring linear displacement along the AP axis (eg using magnetometers or accelerometers)
   b) Measuring changes in chest wall circumference, either physically (strain gauges) or by its effect on thoracic impedance (impedance pneumography)
   c) Measuring changes in cross-sectional area (respiratory inductive plethysmography)
   d) Measuring changes in volume (electromagnetic inductive plethysmography)
2. Methods using external imaging devices
   a) Radiological techniques
   b) Optical techniques

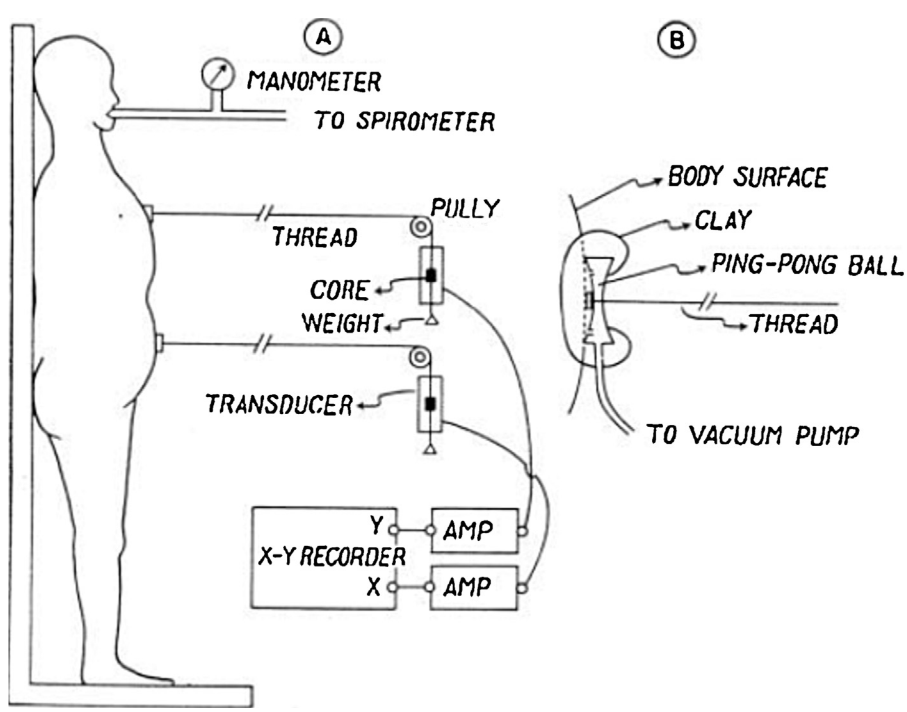

Figure 1. Apparatus designed and used by Konno and Mead to measure chest wall motion. From: Konno K, Mead J. J Appl Physiol 1967 (Reference [1])