Respiratory Gating by Impedance Plethysmography

The study of regional pulmonary ventilation may be improved by synchronization of data acquisition to the respiratory cycle. This synchronization may be achieved by gated acquisition of ventilatory images using spirometric data and analysis of time-activity curves.

Two major problems arise in dynamic pulmonary scintigraphic imaging: inherent variations occur in the respiratory pattern, cycle length, and tidal volume; and the lungs change size and shape continuously during respiration (*1*). The first of these problems involves temporal synchronization, where images obtained during equal increments of time will not necessarily be associated with equal lung volumes. ECG gating of cardiac studies has been very successful because of the close association of the mechanical event following the electrical trigger. This is not the case in respiration, and simply recognizing end-inspiration and end-expiration will not necessarily permit accurate temporal registration of a dynamic scintigraphic image sequence. The second problem relates to the complex spatial relationships within the lung that change instantaneously during the respiratory cycle. The identification of corresponding points within the lungs during the respiratory cycle, even when the global tidal volume is known, is exceedingly difficult. The motion of the lungs during respiration takes place primarily at the bases due to diaphragmatic motion. Coordinate transformations have been performed on scintigraphic series with some success (*2*).

By applying an alternating current (50 to 600 kHz) to bipolar electrodes applied to the chest wall and measuring the transthoracic impedance, the electrical impedance (Z) of the thorax, viewed as a volume conductor, varies approximately linearly with changes in lung volume. Impedance is a measure of the limitation to alternating-current flow in an electrical circuit. There are two major components to impedance, the direct-current resistance and the reactance. If the reactance is zero, the circuit behaves as it would with direct current (DC). For alternating current, Ohm's law becomes:

$$E = IZ,$$

where

E = electrical potential difference in volts,
I = current in amperes,
Z = impedance in ohms.

The resistive component predominates in impedance measurements taken on the body surface, i.e., the reactive component is small. Impedance measurements can be proportional to blood volume, and the difference in resistance observed reflects the volume change. For a uniform current distribution through a homogeneous conductor of uniform cross-sectional area, the change in resistance (ΔR) is (3)

$$\Delta R = -\left(\frac{R_0^2}{\rho L^2}\right)\Delta V$$

where,

R_0 = initial resistance of the conductor
ρ = resistivity
L = length
ΔV = volume change of conducting material

Instantaneous measurements of impedance in the frequency range noted above are available, with the change (ΔZ) predominantly resistive.

Measurement of impedance changes for recording peripheral volume pulses was described first by Mann in 1937 (*4*). Impedance plethysmography has been developed to sense the decrease in im-

pedance with increased volume of blood between two electrodes (*3*). Many clinical applications have been investigated (*5*), especially the noninvasive detection of deep venous thrombosis. Unfortunately, the method has significant drawbacks, including inability; to detect thrombi that do not occlude outflow, to differentiate between thrombotic and nonthrombotic obstruction to venous outflow, and false-positive studies where the calf or thigh muscles are contracted, arterial inflow is reduced, or central venous pressure is raised, reducing venous outflow (*6*).

The major difficulty in quantitative impedance plethysmography lies in the lack of accurate methods to relate the impedance change to a volume change (*3*). Calibration of the impedance measurements in terms of blood flow or respiratory parameters is exceedingly difficult, and accurate quantitative measurements are not readily available (*3*).

Gated regional spirometry, the detection of respiratory organ motion for dynamic pulmonary scintigraphic studies, is usually accomplished by direct measurements on the inspired and expired gas (*2*). Errors due to lack of patient cooperation, uncorrected gas exchange in the lungs during measurement, and gas leakage are associated with the technique. By synchronizing lung images acquired during multiple respiratory cycles using spirometric gating, an averaged series of frames at approximately the same incremental volume may be obtained, commonly using data from time-activity curves. These approaches have found application in the creation of scintigraphic sequences of a reconstructed single respiratory cycle that are viewed dynamically (*7*) similar to gated blood-pool studies of the heart, with potential to form functional images (*8*).

Gated signals obtained from impedance measurements taken from the thorax of intact individuals avoid the quantification problems associated with the modality (*9*). The synchronization of scintigraphic data acquisition with respiratory motion using electrical impedance measurements avoids problems with direct scintigraphic (time-activity curve) or flow spirometric methods (*10*).

Using well-established technology for dynamic scintigraphic data acquisition, Heller and associates (*10*) have demonstrated the utility of simple measurements of electrical-impedance for plethysmographic identification of the phases of the respiratory cycle and synchronization of images with organ motion. They have avoided the registration problem in sequential lung images by creating a scintigraphic series that is viewed dynamically.

The potential for impedance gating to correct for organ motion has been impressively demonstrated.

MICHAEL W. VANNIER, M.D.
Mallinckrodt Institute of Radiology
Washington University School of Medicine
St. Louis, Missouri

REFERENCES

1. ALDERSON PO, LINE BR: Scintigraphic evaluation of regional pulmonary ventilation, *Semin Nucl Med* 10: 218-242, 1980
2. JONES JP: Clinical-imaging studies: Pulmonary. In *Digital Nuclear Medicine*. Erickson JJ, Rollo FD, eds. Philadelphia, JB Lippincott, 1983, 136-145
3. GEDDES LA, BAKER LE: *Principles of Applied Biomedical Instrumentation.* 2nd ed, New York, John Wiley, 1975, 321-330
4. MANN H: Study of peripheral circulation by means of an alternating current bridge. *Proc Soc Exp Biol Med* 36:670-673, 1937
5. NYBOER J: *Electrical Impedance Plethysmography*, 2nd ed, Springfield, Ill., Charles C. Thomas, 1970, 161-181.
6. KAPPERT A.: Venous dynamics and function in noninvasive approach. In *Noninvasive Methods on Cardiovascular Haemodynamics*, Jageneau AHM, ed. New York, Elsevier/North-Holland Biomedical Press, 1981, 229-230
7. GERGANS GA, KAPLAN E, MILO T, et al: Cinescintigraphy of the respiratory cycle with Krypton-81m. In *Digital Imaging: Clinical Advances in Nuclear Medicine*. Esser PD, ed. New York, The Society of Nuclear Medicine, 1982, 291-296
8. MILO T, BARNES WE, KAPLAN E, et al: Functional images derived from lung scintigrams. In *Digital Imaging: Clinical Advances in Nuclear Medicine*, Esser PD, ed. New York, The Society of Nuclear Medicine, 1982, 297-304
9. VANNIER MW: Imaging instruments by CT based on electrical impedance, *J Nucl Med* 22:95, 1981
10. HELLER SL, SCHARF S, HARDOFF R, et al: Cinematic display of respiratory organ motion with impedance techniques. *J Nucl Med* 1127-1131, 1984