Recovery coefficient in PET: The effects of object size and respiratory motion

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Introduction

- Quantitative analysis of PET imaging has become an established method for the staging and prediction of tumor response in some tumor types.
- Signal recovery is deteriorated by limited spatial resolution of PET scanners and respiratory organ motion.
- Characterization of recovery coefficient has been of interest in several groups.
- This work: a realistic breathing model has been used to investigate the combined effects of object size and respiratory motion on signal recovery.

Recovery coefficient:

The ratio of observed to true activity in a PET image
Simulation Study - Method

- Effect of object size (relative to scanner resolution):

  PSF of PET scanner:
  3-D Gaussian with FWHM

  Spherical object of Diameter D
  Scanner FWHM: D \times \frac{1}{2} \times \frac{1}{4} D
  Sphere Diameter: 1 \times \text{FWHM} \quad 2 \times \text{FWHM} \quad 4 \times \text{FWHM}
Respiratory Motion

Respiratory motion model *:

\[ z(t) = z_0 - b \cos^{2n} \left( \frac{\pi t}{\tau} - \phi \right) \]

- \( z_0 \): the position at expiration
- \( b \): the amplitude of the extent of motion
- \( \tau \): the breathing cycle period
- \( \phi \): the starting phase
- \( n \): a shape parameter that determines the degree of post expiratory pause.

Respiratory Motion

Respiratory motion curves:

\( n = 1 \): Short post-expiratory pause

\( n = 3 \): Long post-expiratory pause
Simulation Study - Method

Respiratory motion smear:

Gaussian-smeared Image, \( D = 2 \times \text{FWHM} \)

Breathing shape factor \( n = 1 \)

Breathing shape factor \( n = 3 \)

Motion amplitude: \( b = 1 \times \text{FWHM} \)  \( b = 2 \times \text{FWHM} \)  \( b = 4 \times \text{FWHM} \)
Simulation Study - Method

Respiratory gating:

Un-gated image

\[ D = 2 \times \text{FWHM} \]

\[ b = 4 \times \text{FWHM} \]

\[ n = 3 \]

4 – bin gating

8 – bin gating
Simulation Study - Results

Breathing motion parameter $n=1$
- Motion amplitude, $b/FWHM = 0$
- Motion amplitude, $b/FWHM = 4$

Breathing motion parameter $n=3$
- Motion amplitude, $b/FWHM = 0$
- Motion amplitude, $b/FWHM = 4$

Recovery coefficient - RC

Sphax diameter - D/FWHM

Respiratory motion

Organ position

Time, t/cycle period
Experimental Validation

• GE Discovery LS PET scanner with a Real-Time Position Management (RPM) System (Varian)
  – Slice spacing: 4.25 mm
  – FWHM: ~5.5 mm

• A motion phantom with a computer-controlled step motor to move eight hot spheres (Data Spectrum) through water.
  – Object-to-background activity concentration ratio: 8.3:1.
  – Sphere inner diameters: 4.0, 6.2, 7.9, 9.9, 12.4, 15.4, 19.8 and 31.3 mm.
  – The motion amplitudes: 5.5, 11, 16.5 and 22 mm
  – Shape factors: $n = 1$ and $n = 3$
  – Breathing cycle period: 3.0 seconds
  – Respiratory gating: 4 bins and 8 bins, for motion amplitude of 11 mm and 22 mm.
Experimental study - Phantom
Experimental study – Results (1)

- **shape factor n = 1**
  - Motion amplitude:
    - 0
    - 5.5 mm
    - 11 mm
    - 16.5 mm
    - 22 mm

- **shape factor n = 3**
  - Motion amplitude:
    - 0
    - 5.5 mm
    - 11 mm
    - 16.5 mm
    - 22 mm
Experimental study – Results (2)
Comparison

Other possible factors:
- Attenuation correction
- Scatters
- Randoms
- Normalization
- Dead time
- Noise
Conclusion

• For a stationary spherical object, signal loss is significant for small objects.
• Signal intensity of small objects already compromised by limited spatial resolution is further degraded due to respiratory motion.
• The recovery coefficient is relatively less affected by respiratory motion with greater post expiratory pause.
• Signal recovery affected by respiratory motion can be partially reversed by respiratory gating.
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