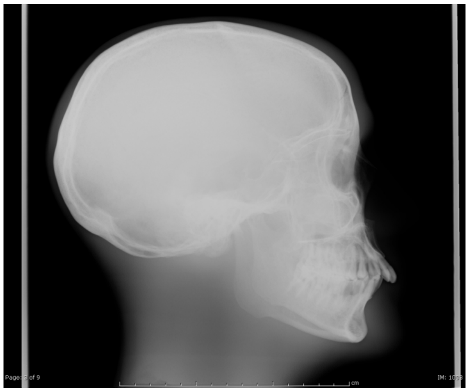
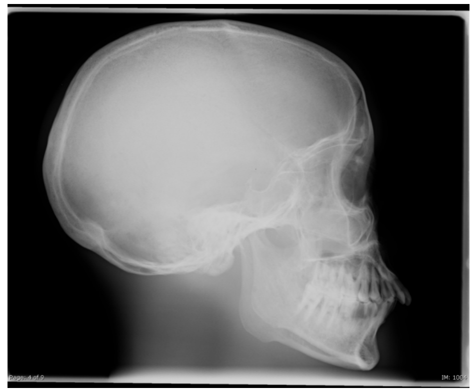
Scattered Radiation and X-Ray Grids

1. Motivation

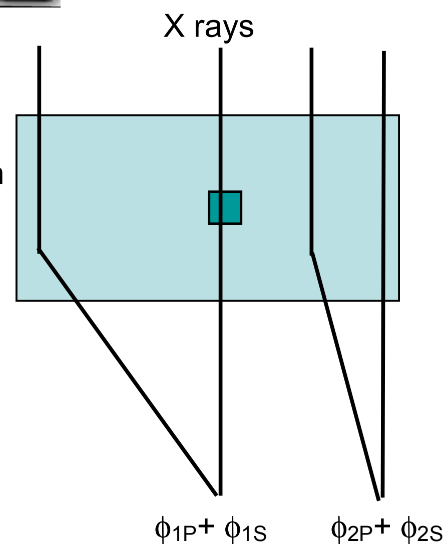
with scatter



with reduced scatter



In addition to image quality reduction,
scatter radiation is also important in:
1. CT – causes cupping artifact
2. Dual-energy imaging – causes inaccuracies in weight function
3. Quantitative imaging – causes inaccuracies



2. Effects of Scatter

2.A. Contrast

2.A.i. No Scatter

The radiation contrast in the absence of scatter is

$$C_{NS} = \frac{\Delta\phi}{\bar{\phi}} = \frac{\phi_1 - \phi_2}{\left[\phi_1 + \phi_2\right]/2} = \frac{\phi_{1P} - \phi_{2P}}{\left[\phi_{1P} + \phi_{2P}\right]/2} \quad . \qquad [1]$$

2.A.ii. With Scatter

$$C_S = \frac{\Delta\phi}{\bar{\phi}} = \frac{\phi_1 - \phi_2}{\left[\phi_1 + \phi_2\right]/2} = \frac{(\phi_{1P} + \phi_{1S}) - (\phi_{2P} + \phi_{2S})}{\left[(\phi_{1P} + \phi_{1S}) + (\phi_{2P} + \phi_{2S})\right]/2} \quad . \qquad [2]$$

Assuming $\phi_{1S} = \phi_{2S} = \phi_S$, then

$$C_S = \frac{\Delta\phi}{\bar{\phi}} = \frac{\phi_1 - \phi_2}{\left[\phi_1 + \phi_2\right]/2} = \frac{(\phi_{1P} + \phi_{1S}) - (\phi_{2P} + \phi_{2S})}{\left[\phi_{1P} + \phi_{2P}\right]/2 + \phi_S} = C_{NS} \frac{\left[\phi_{1P} + \phi_{2P}\right]/2}{\left[\phi_{1P} + \phi_{2P}\right]/2 + \phi_S} \qquad [3]$$

$$C_S = C_{NS} \frac{P}{P+S} \qquad [4]$$

where $P = \dfrac{(\phi_{1P} + \phi_{2P})}{2}$ and $S = \phi_S$.
Therefore

$$C_S = C_{NS}(1 - SF) \quad [5]$$

and

$$\frac{C_S}{C_{NS}} = (1 - SF) \quad [6]$$

where $SF = \dfrac{S}{P+S}$ is the scatter fraction. Also S/P is the scatter-to-primary ratio and

$1 - SF = \dfrac{1}{1 + S/P}$

For a screen-film system, the radiographic contrast is

$$\Delta D = G(\log_{10} e)\frac{\Delta E}{E} \quad [7]$$

but $E = k\phi$ [8]

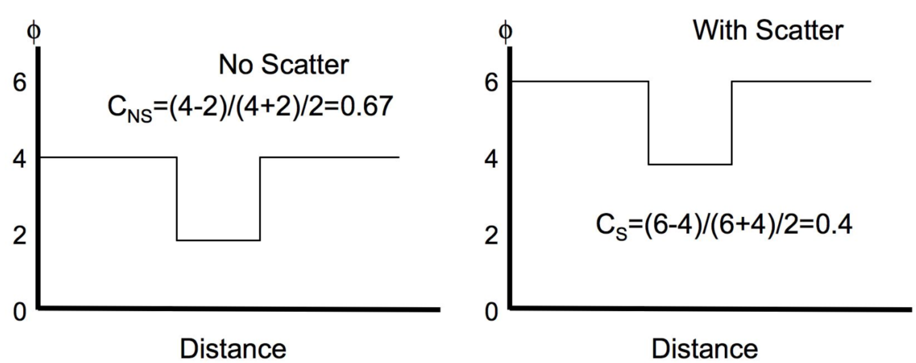
$\therefore \Delta E = k\Delta\phi$

$\dfrac{\Delta E}{E} = \dfrac{\Delta\phi}{\phi} \approx C$ for $\phi_1 \approx \phi_2 \approx \overline{\phi}$.

$\Delta D = CG(\log_{10} e)$ i.e., $\Delta D_S = C_S G(\log_{10} e)$ and $\Delta D_{NS} = C_{NS} G(\log_{10} e)$ [9]

$$\therefore \frac{\Delta D_S}{\Delta D_{NS}} = (1 - SF) = \frac{C_s}{C_{NS}} \quad [10]$$

Illustration of correcting for scatter by subtraction (contrast only)



If you subtract 2 from each pixel in the “With Scatter” case you will recover the “No Scatter” contrast. If you subtract 4 from each pixel you will get 100% contrast!

2.B. SNR

Recall

$$SNR = C\sqrt{A\overline{\phi}} \quad [11]$$

Therefore, SNR no scatter is

$$SNR_{NS} = C_{NS}\sqrt{A\bar{\phi}_P} \quad [12]$$

and the SNR with scatter is

$$SNR_S = C_S\sqrt{A\left(\bar{\phi}_P + \bar{\phi}_S\right)} \quad [13]$$

Therefore

$$\frac{SNR_s}{SNR_{NS}} = \frac{C_s}{c_{NS}}\sqrt{\frac{A\left(\bar{\phi}_P + \bar{\phi}_s\right)}{A\bar{\phi}_P}} = \frac{\bar{\phi}_P}{\bar{\phi}_P + \bar{\phi}_s}\sqrt{\frac{\bar{\phi}_P + \bar{\phi}_s}{\bar{\phi}_P}} = \sqrt{\frac{\bar{\phi}_P}{\bar{\phi}_P + \bar{\phi}_s}} \quad [14]$$

$$\frac{SNR_s}{SNR_{NS}} = \sqrt{1-SF} \quad [15]$$

This assumes constant patient exposure.

For constant detector exposure (necessary for screen-film screen systems), then the SNR no scatter becomes

$$SNR_{NS} = C_{NS}\sqrt{A\bar{\phi}_P{}'} \quad [16]$$

where $\bar{\phi}'_P$ is the modified fluence after compensating for the missing scatter.

$$\frac{SNR_s}{SNR_{NS}} = \frac{C_s}{c_{NS}}\sqrt{\frac{\bar{\phi}_P + \bar{\phi}_s}{\bar{\phi}'_P}} = \frac{\bar{\phi}_P}{\bar{\phi}_P + \bar{\phi}_s}\sqrt{\frac{\bar{\phi}_P + \bar{\phi}_s}{\bar{\phi}'_P}} = \frac{\bar{\phi}_P}{\sqrt{\bar{\phi}_P{}'\left(\bar{\phi}_P + \bar{\phi}_s\right)}} \quad [17]$$

but $\overline{\phi'_P} = \bar{\phi}_P + \bar{\phi}_S$

$$\frac{SNR_s}{SNR_{NS}} = \frac{\bar{\phi}_P}{\sqrt{\left(\bar{\phi}_P + \bar{\phi}_s\right)\left(\bar{\phi}_P + \bar{\phi}_s\right)}} = \frac{\bar{\phi}_P}{\left(\bar{\phi}_P + \bar{\phi}_s\right)} = 1-SF \quad [18]$$

$$\frac{SNR_s}{SNR_{NS}} = \begin{cases} 1-SF & \text{for constant screen exposure (screen-film systems)} \\ \sqrt{1-SF} & \text{for constant patient exposure (digital or linear systems)} \end{cases}$$

SF ranges from 0 to 1.0, with 0=no scatter and 1= full scatter.

Typically, SF in mammography is 0.2-0.5 for mammography (low kVp) and 0.5-0.9 for general radiography, with a value of 0.9 for abdominal imaging of an obese person.

3. Causes of Scatter

Physical mechanism of scatter:

1.
2.
3.

4. Magnitude of Scatter

1. Atomic number. bone vs. water vs. air

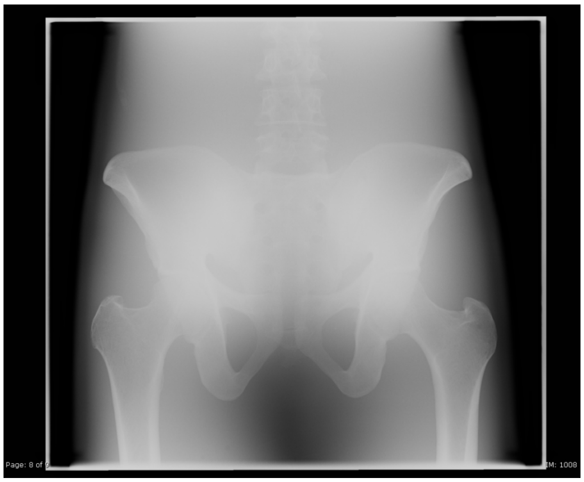
2. X-ray energy

3. Patient thickness

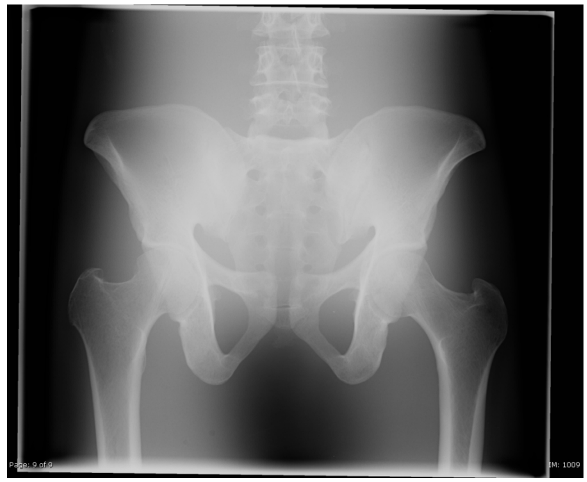
4. Field size

5. Irradiation geometry

6. Performance of anti-scatter device



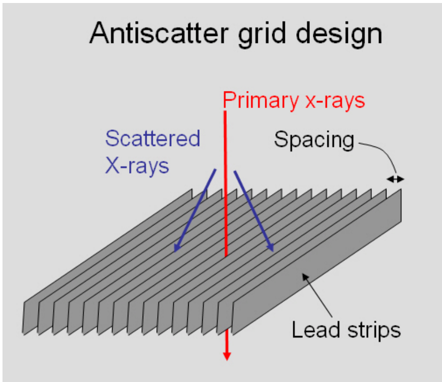
No grid

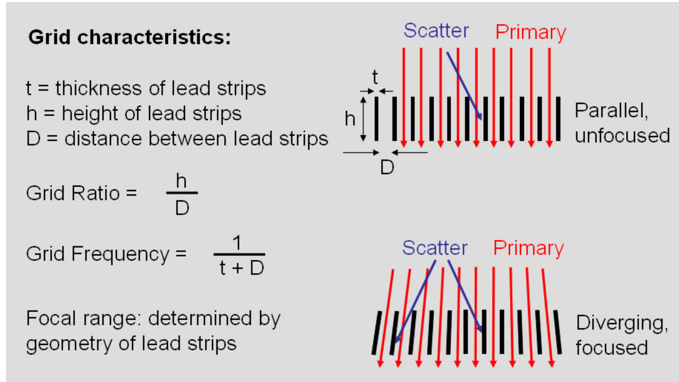


Grid

5. Methods of Reducing Scatter

6. Evaluation of Grids





1. Primary Transmission

$$T_P = \frac{\phi_{P_{grid}}}{\phi_{P_{nogrid}}} X100\% \qquad [19]$$

Typically, T_P is 60%-70%

2. Bucky Factor

The Bucky factor, B, is the ratio of the incident radiation divided by the transmitted radiation.

$$B = \frac{P_{nogrid} + S_{nogrid}}{P_{grid} + S_{grid}} \qquad [20]$$

This is the factor by which the patient exposure needs to be increased when a grid is used to maintain the same film optical density as when no grid is used. It accounts to primary and scatter attenuation in the grid.

3. Contrast Improvement Factor

The contrast improvement factor, K, is the ratio of the contrast with a grid to the contrast without a grid.

$$K = \frac{C_{grid}}{C_{nogrid}} = \frac{\Delta\phi_{grid}}{\bar{\phi}_{grid}} x \frac{\bar{\phi}_{nogrid}}{\Delta\phi_{nogrid}} = \frac{\Delta\phi_{P_{grid}}}{\bar{\phi}_{P_{grid}} + \bar{\phi}_{S_{grid}}} \frac{\bar{\phi}_{P_{nogrid}} + \bar{\phi}_{S_{nogrid}}}{\Delta\phi_{P_{nogrid}}} \qquad [21]$$

Then, using Eqs. [19] and [20], Eq. [21] becomes:

$$K = T_p B \qquad [22]$$

7. Spatial Distribution of Scatter

For mathematical details, see Barrett and Swindell pp. 578-580.

Drawing of line profile with and without scatter

Drawings of PSF of detector, scatter, and total along with MTF of the three.