Radiation Dose Optimization for Critical Organs in Interventional Radiology

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Assumptions
- Imaging modality: Fluoroscopically Guided Interventional (FGI),
- The X-ray passes through the patient→ attenuated while interacting with the different internal structures of the body⇒ a shadow of the structures constructs the digital image.
- Two major types of risks: deterministic (skin injuries) and stochastic effects (cancer induction).
- Any amount of the absorbed radiation in the body ∝ a risk of cancer induction

FGI Modality
Siemens.medical.com

Motivation
- More than 700,000 fluoroscopy examinations are performed everyday in US [7].
- A linear, no-threshold (LNT) model illustrates the dose and cancer risk relationship (Nuclear Regulatory Commission (NRC)).
- A study on women who received chest X-ray: young women who receive repeated X-rays with breast tissue included in the beam interception region with body, have about 9 times higher potential risk of breast cancer for the ages ≤40 in compare with ages >40 [7].

Mathematical Model
\[
\begin{align*}
\text{Min} & \quad \sum \psi_{(i,j,l)}(x,y) \in C_o \text{dose}_x \psi_{(i,j,l)} = \sum_{(i,j,l)} \sum_{x,y} \sum_{i,j,l} \gamma_{i,j,l}^{x,y} = \sum_{x,y} \sum_{i,j,l} \mu_{i,j,l}^{x,y} \\
\text{Subject to} & \quad \gamma_{i,j,l}^{x,y} \leq \eta^{x,y} \quad (1) \\
& \quad \gamma_{i,j,l}^{x,y} \leq \delta^{x,y} \quad (2) \\
& \quad \gamma_{i,j,l}^{x,y} \geq \eta^{x,y} + \delta^{x,y} - 1 \quad (3) \\
& \quad \delta^{x,y} \geq \delta^{x,y} + \delta^{x,y} - 1 \quad (4) \\
& \quad p \leq j \leq t, \quad p = 1, \ldots, n - 2, t = p + 2, \ldots, n \\
& \quad \gamma_{i,j,l}^{x,y} \geq \eta^{x,y} + \eta^{x,y} - 1 \quad (5) \\
& \quad k \leq j \leq h, \quad k = 1, \ldots, n - 2, h = k + 2, \ldots, n. \\
\end{align*}
\]

Notations
- \(E_0\): Initial energy of each beam at source.
- \(E_{0p}^{i,j,l}, x,y\) : energy of beamlet at level \(l\).
- \(\gamma_{i,j,l}^{x,y}\): indicator of beamlet existence in the field of radiation.
- \(x, y, z\) : table increments in each direction.
- \(\psi_{(i,j,l)}^{x,y}\) : indicator of voxel \(i, j, l\) of body interception with beamlet \(i,j\).

Results
Using polyhedral analysis, we added strong valid inequalities to the lazy cut pool. We solved a number of test problems for cardiovascular exams where patient breasts are critical organs and patient heart is organ of interest. Then we added some search algorithms to the preprocessing step of CPLEX12.

- Adding Strong Valid Inequalities
- Adding Search Algorithm

Objective
To provide a setting for the equipment in terms of geometry and energy which minimizes the absorbed dose in a critical organ while maintaining image quality.

Introduction
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Assumptions
- Patient and image are discretized in pseudo voxels with equal size.
- A set of CT images are used for the estimate of attenuation coefficient for each voxel at a given kV.
- Table attenuation is not considered for each in the computations.
- The distance traversed in each pseudo voxel by the pencil beam is assumed to be equal.
- Energy of the beam is uniformly distributed and equal for each pencil beam.
- Each pencil beam is emitted from the X-ray source to the center of a pseudo pixel in the image.

X-ray Attenuation