Calculation of Effective Doses for Radiotherapy Cone-Beam CT and Nuclear Medicine Hawkeye CT

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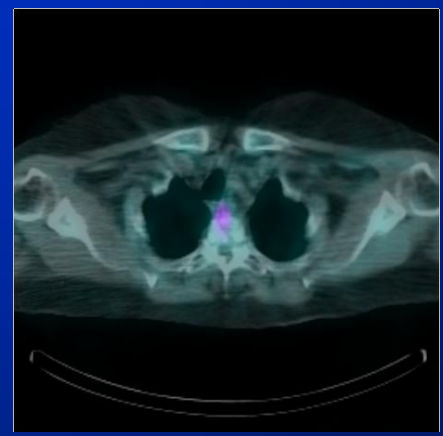
Overview

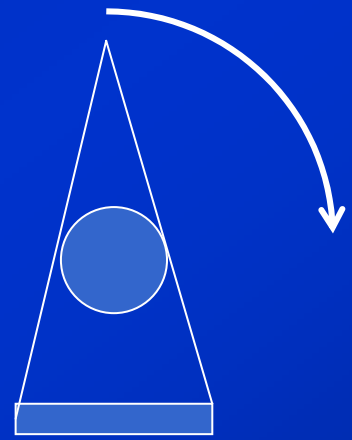
- Varian Acuity ConeBeam CT
  - ConeBeam CT option available Sept 2005
  - Aim to use for breast and pelvis treatment planning

- GE Infinia Hawkeye SPECT / CT
  - Installed in March 2006
  - Enables registration of CT and Nuclear Medicine Images

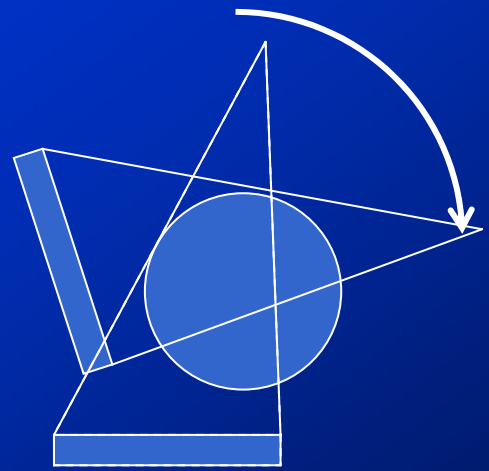


ConeBeam CT

- Full Fan
  - irradiates uniformly over 360º
  - Single rotation produces full image

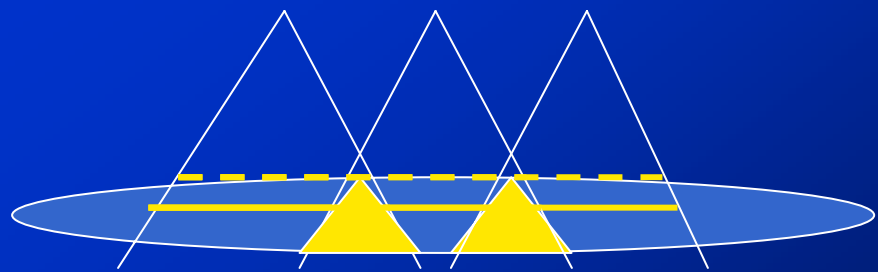


- Partial Fan
  - for larger fields of view
  - Detector is offset
  - Centre of field of view is irradiated for whole rotation
  - Edge of field of view is irradiated for fraction of the rotation



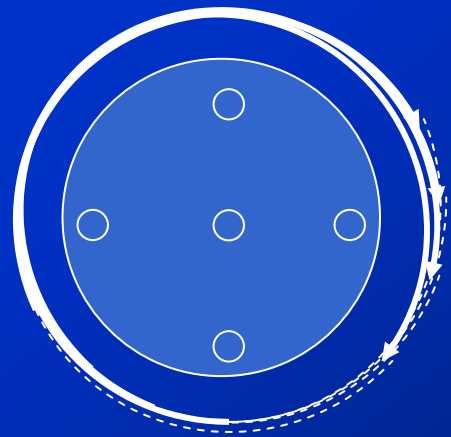
ConeBeam CT

- System upgrade in October 2006
  - Allows images to be ‘stitched’
  - Images are acquired in 1, 2 or 3 rotations.
  - Images acquired using a single rotation can be collimated
  - Irradiated length at isocentre exceeds image length
  - For double and triple scans, irradiation at the isocentre overlaps at stitching area
    - 10cm overlap for 2.5mm slice width
    - 13.6cm overlap for 10mm slice width
  - It is not possible to collimate double and triple scans



Infinia Hawkeye CT

- All clinical scans use ‘half scan’ setting
  - 240º exposure per 360º rotation
- Rotational increment programmed between slices
  - Changes the 240º section irradiated



Doses were measured using CTDI head and body phantoms (16cm and 32cm diameters)

Effective Dose Calculations

Three calculation methods were compared:

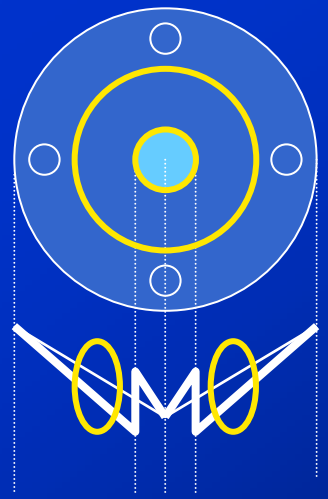
1. IMPACT CT Patient Dosimetry Calculator
2. Combination of tissue weighting factors and fraction of organs in the beam
3. NRPB W-67 Effective dose conversion factors

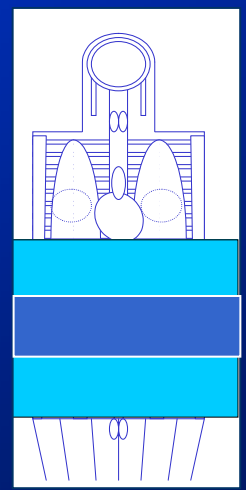
IMPACT CT Patient Dosimetry Calculator

- Each scanner was matched to an existing CT scanner
  - Using ratio of dose measurements in air, to doses at centre and periphery of head and body phantoms
- Both scanners use maximum exposure parameters
  - ConeBeam CT: 125kV, 80mA, 15ms pulse, 45s rotation
  - Infinia Hawkeye: 140kV, 2.5mA, 2.6rpm, 10mm slice

IMPACT CT Patient Dosimetry Calculator for ConeBeam CT

- Assumes uniform irradiation
  - Correct for ConeBeam CT full fan
- Estimation only for partial fan
  - Assumes gradual variation in dose
  - Small high dose area at centre
  - Doses to organs between centre and periphery of body will be overestimated
    - E.g. lung, colon, stomach, liver
- For double and triple scans
  - Calculate dose for full scan length
  - Add dose at stitching overlap





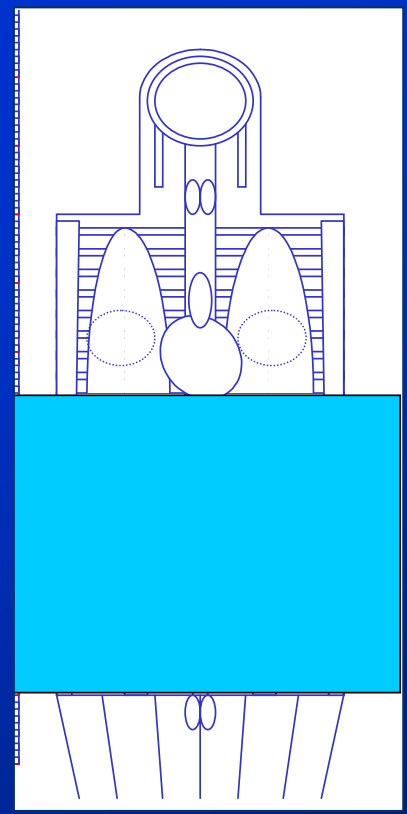
IMPACT CT Patient Dosimetry Calculator for Infinia Hawkeye

- Variation in dose around periphery
  - Due to 240º irradiation
  - And couch attenuation

- Average peripheral dose used for scanner match
  - Irradiated area varies due to rotation increment between slices
  - Organs exceeding 15cm length will receive approximately uniform irradiation
  - Dose will be underestimated if small radiosensitive organ is at irradiated surface e.g. thyroid

Organ Fractions Calculation

- Estimate fraction of each radiosensitive organ in the beam for common scans
  - Using IMPACT phantom
- Multiply by measured dose in phantom
- Multiply by tissue weighting factors
- Sum results for all organs



Organ Fractions Calculation: Infinia Hawkeye

- Clinical settings, with ‘half scan’
  - Average peripheral dose: 4mGy
  - Central dose: 2mGy

Chest scan	Weighting factor	CTDI (mGy)	Fraction in beam	Organ dose
Lung	0.12	2	1	0.24
Stomach	0.12	2	0.1	0.02
Thyroid	0.05	4	0.2	0.04
Total				0.8

Organ Fractions Calculation: ConeBeam CT

- Partial fan for body scans
  - Average periphery: 20mGy
  - Centre: 12mGy
  - Average mid-points: 14mGy
- Dose measurements at mid-points correspond to dose at edge of head phantom
  - Apply mid-point doses to lung, stomach, liver
- For double and triple scans
  - Calculate dose for total scan length
  - Add dose for overlap in centre of scan

NRPB W-67 Effective Dose Conversion Factors

- Calculate dose length product:
  - CTDI (mGy/mAs)
  - mAs = mA x rotation time (x pulse length x frame rate)
  - Scan length
- Effective doses per DLP (mSv (mSv cm)$^{-1}$)
  - Head: 0.0021
  - Chest: 0.014
  - Abdo-pelvis: 0.015

Comparison of Methods for Infinia Hawkeye

Effective dose (mSv)	Chest	Abdo-pelvis	Head
IMPACT	1.0	1.6	0.10
Organ fraction	0.8	1.5	0.12
Conversion factors	0.9	1.5	0.11
Standard CT	2.6	6.2	1.4

- Standard scan lengths used in CT
- Good agreement between calculation methods
- Effective doses lower than standard CT due to low mAs

Comparison of Methods for ConeBeam CT (single scan)

Effective Dose (mGy)	Chest	Abdo-pelvis	Head
IMPACT	9.9	10	1.7
Organ fraction	4.7	5.3	1.4
Conversion factors	5.8	6.2	1.8
Standard CT	2.6	6.2	1.4

- **IMPACT calculation**: Overestimates doses to organs between centre and periphery of body
- **Organ fraction method**: Underestimates dose due to exclusion of scattered radiation to organs outside beam

ConeBeam CT: Stitched Images

- A single scan will produce a maximum image length of 14.4cm
- Data from 2 rotations may be stitched to produce a maximum image length of 28.8cm
  - Total image length depends on slice width selected
  - Overlap in centre of image depends on slice width
  - Total irradiated length is independent of slice width
  - Therefore, effective dose has negligible dependence on slice width
- Abdo-pelvis scans generally use double scan

Summary: Calculation Methods

- Infinia Hawkeye CT
  - Methods for calculating effective dose are in good agreement with one another
- ConeBeam CT
  - There is significant variation in doses
    - IMPACT method overestimates dose
    - Organ fraction method underestimates dose

Summary: Effective Doses

- Hawkeye doses are below diagnostic CT results
  - Half-scan setting is used for all patients
  - Scan length is determined individually for each patient
  - No option to reduce kV or mA
- ConeBeam CT doses may significantly exceed diagnostic CT doses
  - No option to reduce kV, mA
  - Recommendations:
    - Single scan should be used wherever possible
    - Longer pulse lengths only used for very low contrast details
    - Slice widths of 3-5mm compromise between data storage, reconstruction times, and prevention of double overlap
    - Double and triple scans only used where clinically justified