- **IMRT, IGRT, SRS and SBRT**

-----The Physics behind it

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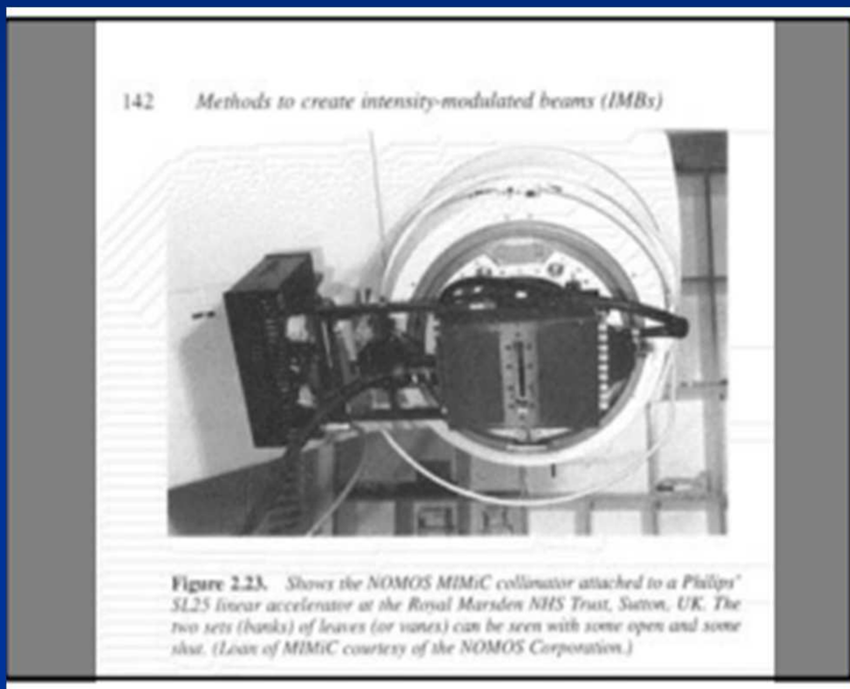
Pune.

- IMRT was proposed by Dr.Anders Brahme in 1982. ”? •
- • 1988 – one person knew about IMRT – Anders Brahme
- • 1995 - main planning and delivery techniques worked out •
- 2000 – all major companies offering products
- • 2003 – “everyone wants IMRT”. • So: is there anything left to do? Students, postdocs, managers, bean counters all ask this. • No! IGRT, non-MLC IMRT, Co-IMRT, MMI applied to IMRT, IMRT and molecular genetics.

- 1982 Brahme et al discussed inverse-planning for a fairly special case of rotational symmetry.
- 1984 First commercial MLCs appeared.
- 1988 Brahme published first paper on algebraic inverse planning.
- 1988 Källman postulated dynamic therapy with moving jaws.
- 1989 Webb developed simulated annealing for inverse planning. So did Mageras and Mohan.
- 1990 Bortfeld developed algebraic/iterative inverse-planning, the precursor of the KONRAD treatment-planning system.
- 1991 Principle of segmented-field therapy developed (Boyer / Webb).

- 1992 Convery showed the dMLC technique was possible.
- 1992 Carol first showed the NOMOS MIMiC and associated PEACOCKPLAN planning system (now CORVUS).
- 1993 Tomotherapy (the Wisconsin machine) first described by Mackie.
- 1994 Stein, Svensson and Spirou independently discovered the optimal dMLC trajectory equations.
- 1994 Bortfeld and Boyer conducted the first multiple static-field (MSF) experiments.
- 2002 Commercial tomotherapy began



142 *Methods to create intensity-modulated beams (IMBs)*

Figure 2.23. *Shows the NOMOS MIMiC collimator attached to a Philips' SL25 linear accelerator at the Royal Marsden NHS Trust, Sutton, UK. The two sets (banks) of leaves (or vanes) can be seen with some open and some shut. (Loan of MIMiC courtesy of the NOMOS Corporation.)*

- ‘IMRT is a radiation treatment technique with multiple beams in which at least some of the beams are intensity-modulated and intentionally deliver a non-uniform intensity to the target. The desired dose distribution in the target is achieved after superimposing such beams from different directions. The additional degrees of freedom are utilized to achieve a better target dose conformality and/or better sparing of critical structures’.

INSTITUTE OF PHYSICS PUBLISHING — PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **51** (2006) R363–R379 — doi:10.1088/0031-9155/51/13/R21

REVIEW

IMRT: a review and preview

Thomas Bortfeld

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- Where does “Inverse Planning” term come?
- Once, a planning objective was made, saying X Gy for PTV and Y Gy for nearby critical organ(s), using 5-10 beams, they tried to find the modulation required in each beam, which is non negative and that is why the term came.

- Fields X Modulation= desired dose distribution

Why "Inverse"

DOSE SPACE LINKED BEAM SPACE	*	BEAM WEIGHT VECTOR	=	DOSE DISTRIBUTION

$$A * b = D$$

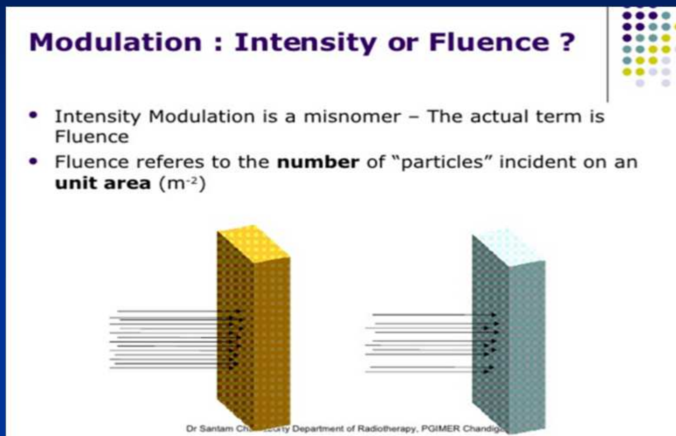
$$b = A^{-1} B$$

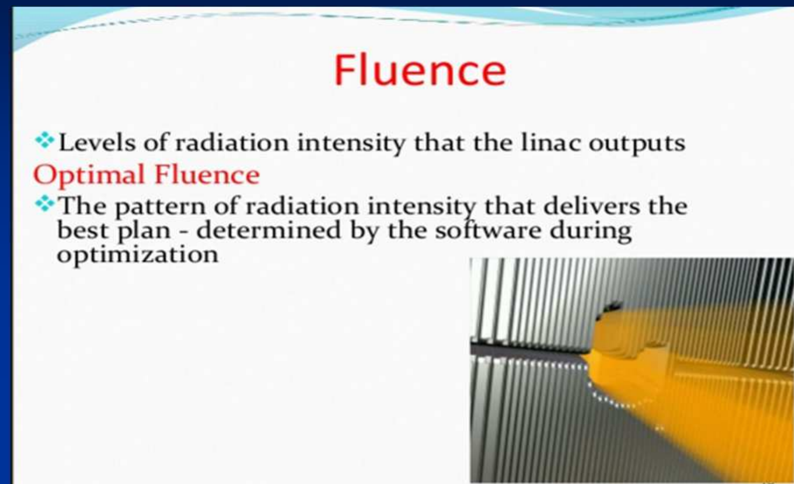
Cost function

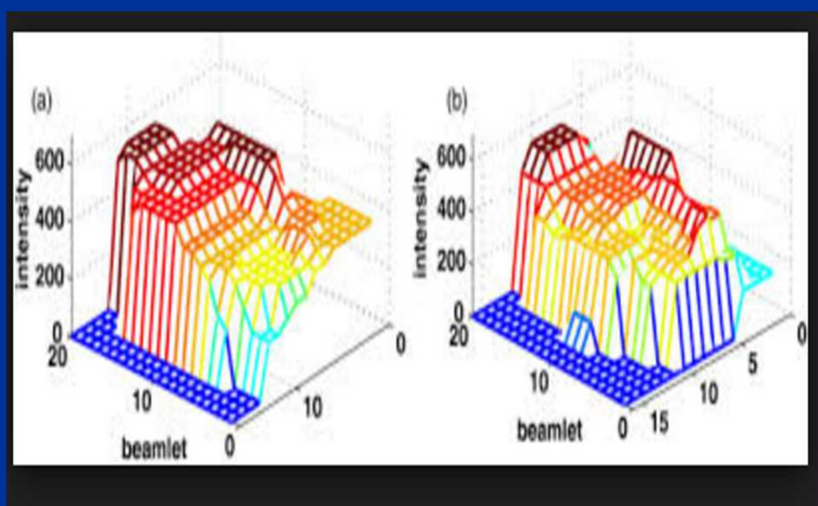
$$\text{cost} = \sum \mathrm{I}(x,y,z)[\boldsymbol{D}(x,y,z) - \boldsymbol{D}^{\mathrm{p}}(x,y,z)]^2$$

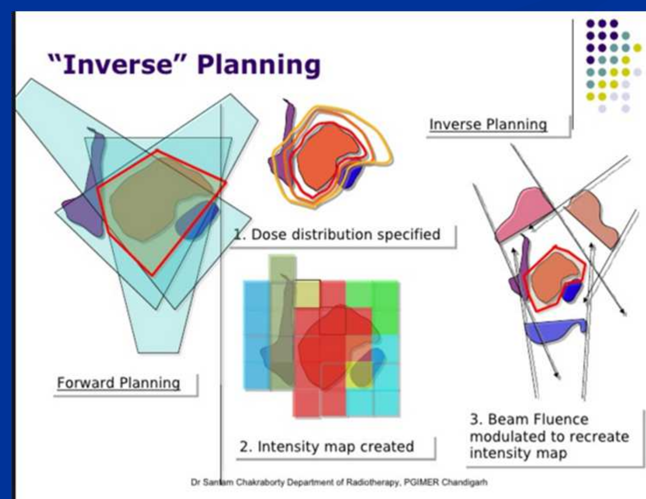
$$(\text{Dose}_{\text{prescribed}} - \text{Dose}_{\text{delivered}})^2$$

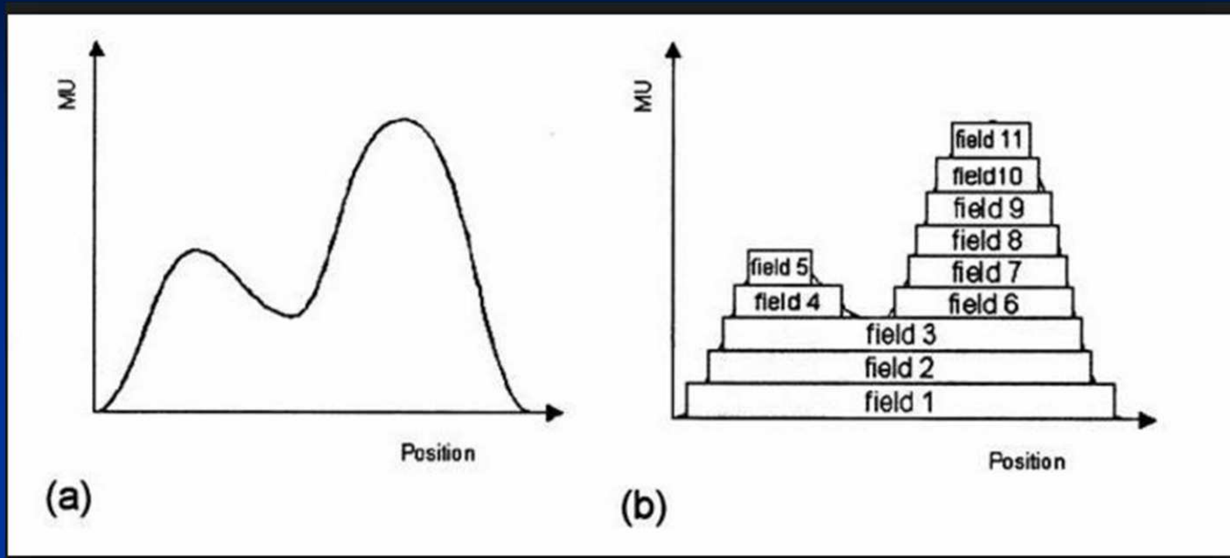
Steve Webb(1989)--was probably the first who published a paper about the formulation of the inverse problem of IMRT as an optimization problem (Webb 1989), minimizing an objective function or 'cost function'.

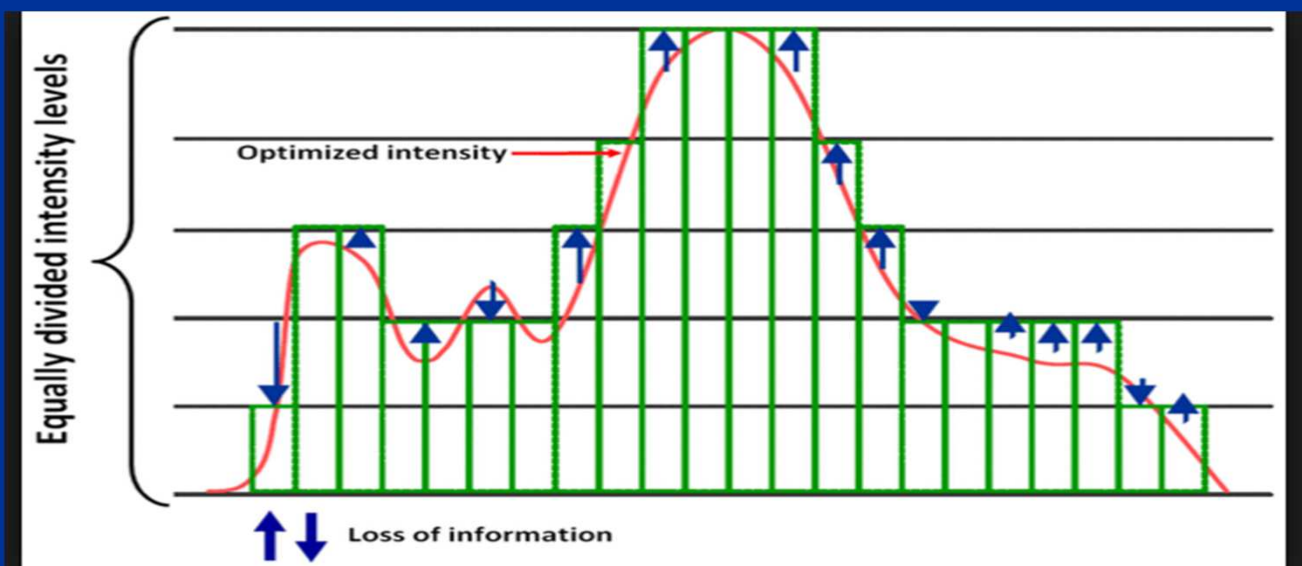

Modulation : Intensity or Fluence ?
Intensity Modulation is a misnomer – The actual term is Fluence
Fluence referes to the number of "particles" incident on an unit area (m-2)

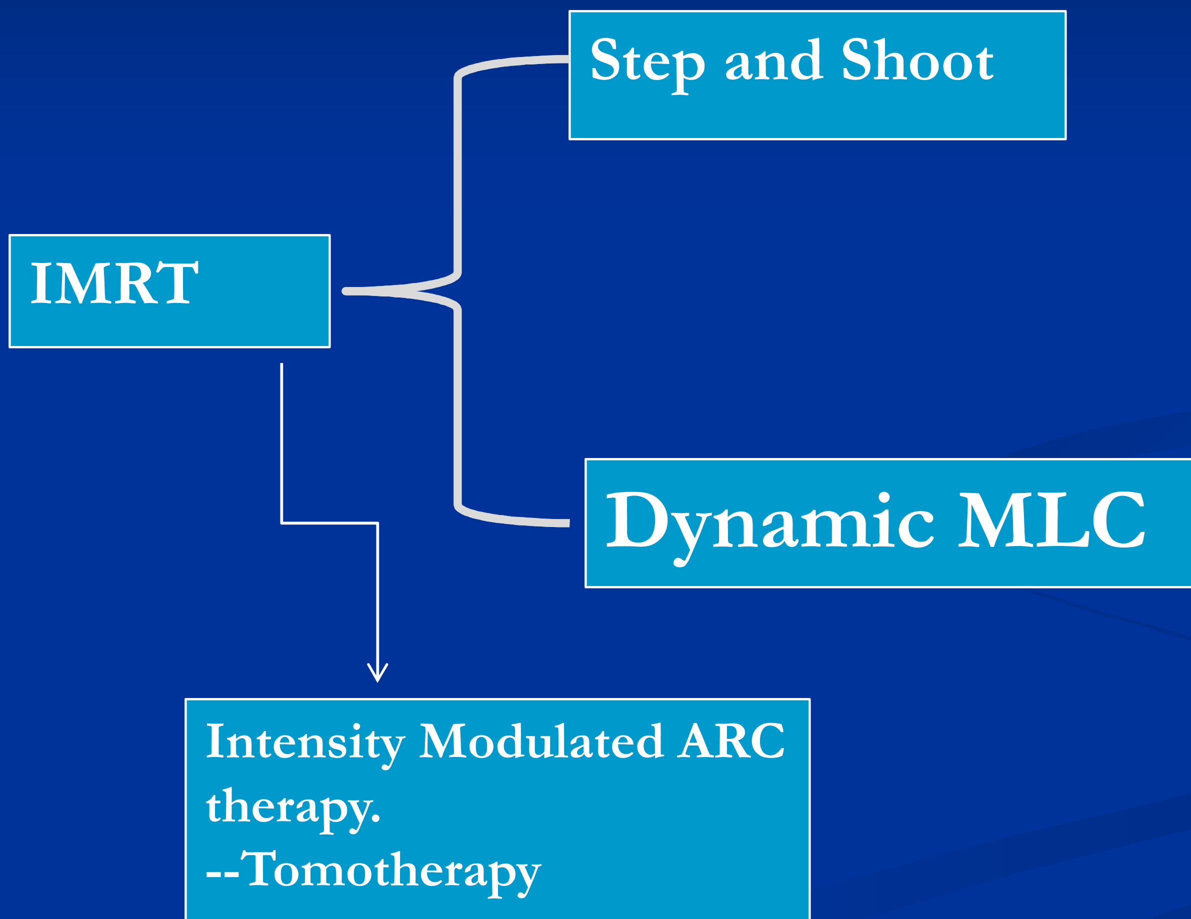

Fluence
Levels of radiation intensity that the linac outputs
Optimal Fluence
The pattern of radiation intensity that delivers the best plan - determined by the software during optimization


(a)
intensity
600
400
200
0
20
10
beamlet
0
10
0
(b)
intensity
600
400
200
0
20
10
beamlet
0
15
10
5
0


"Inverse" Planning
Inverse Planning
Dose distribution specified
Forward Planning
2. Intensity map created
3. Beam Fluence modulated to recreate intensity map
Dr Santam Chakraborty Department of Radiotherapy, PGIMER Chandigarh


MU
Position
(a)
MU
field 11
field10
field 9
field 8
field 7
field 6
field 5
field 4
field 3
field 2
field 1
Position
(b)


Equally divided intensity levels
Optimized intensity
Loss of information

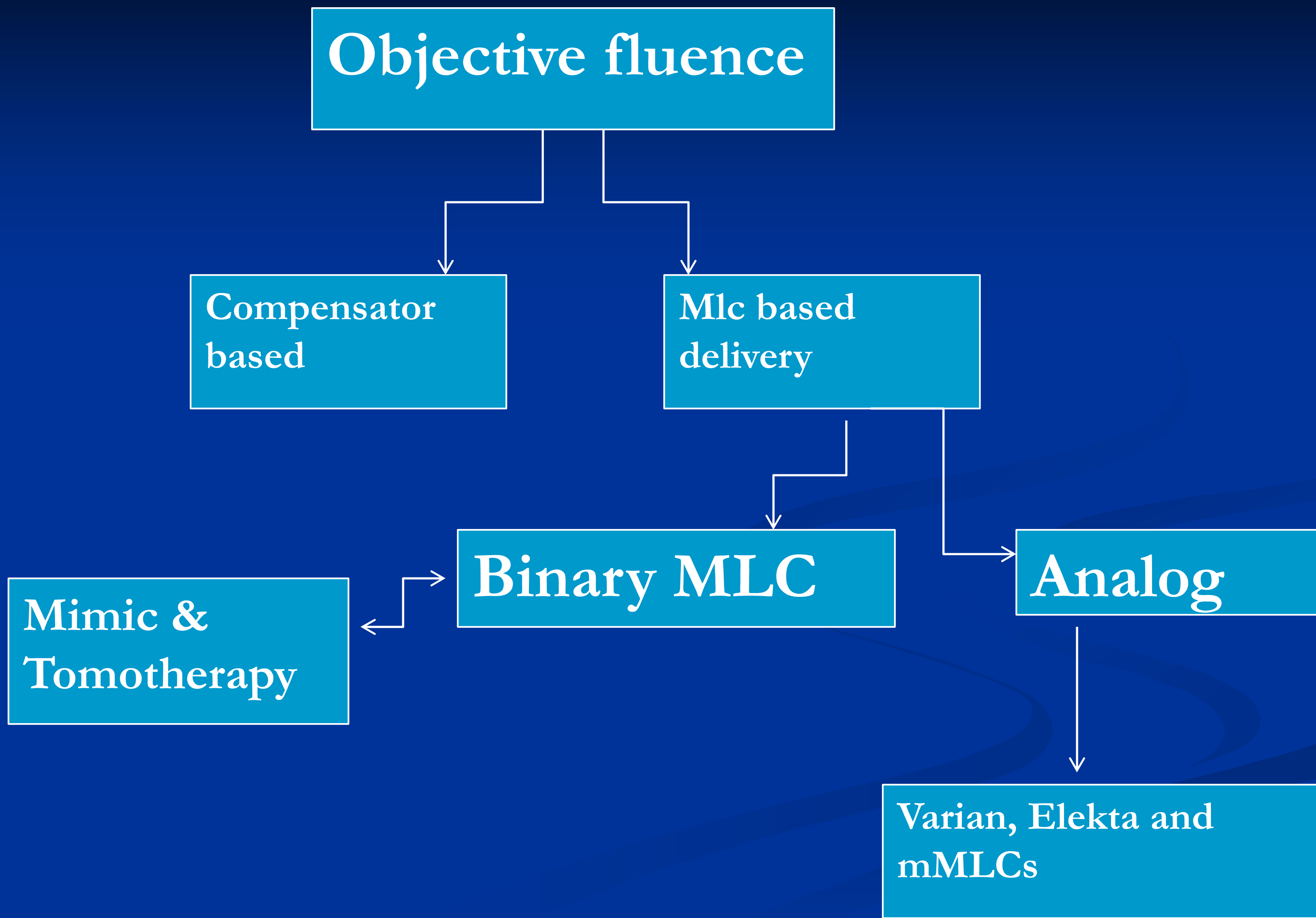

Step and Shoot
IMRT
Dynamic MLC
Intensity Modulated ARC therapy.
--Tomotherapy

IMRT DELIVERY

- Having calculated the fluence distributions or fluence maps for each field angle, one now needs to have a means of delivering those fluence maps.
- Methods to deliver an IMRT treatment are:
  - Compensator based IMRT
  - Multileaf collimator (MLC) based
    - Static or step & shoot mode
    - Dynamic mode
  - Intensity modulated arc therapy (IMAT)
  - Tomotherapy

- During the optimization process, each beam is divided into small "beamlets"
- Intensity of each is varied until the optimal dose distribution is derived

- We can Optimize following parameters
  - **Intensity maps**
  - **Number of intensity levels**
  - Beam angles
  - Number of beams
  - Beam Energy


Objective fluence
Compensator based
Mlc based delivery
Binary MLC
Analog
Mimic & Tomotherapy
Varian, Elekta and mMLCs

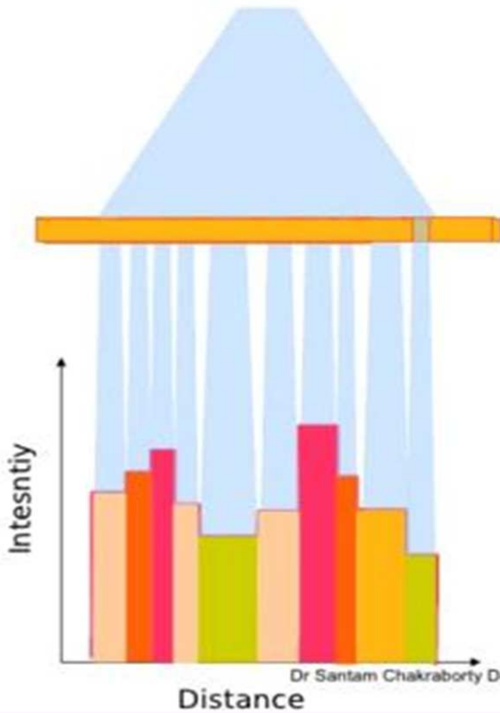
A-segmental MLC Delivery

- In segmental MLC (SMLC) delivery the patients is treated by multiple field and each field is subdivided into a set of subfield with uniform beam intensity level.
- The subfield are created by the MLC and delivered in a stack arrangement one at a time in sequence without operator intervention.
- The accelerator is turned off while the MLC moves to create next subfield.
- This method of IMRT delivery is also called ***"step and shoot OR stop and shoot***

B- Dynamic MLC Delivery(DMLC)

- Unlike SMLC.
- In the dynamic OR sliding window mode ,the leaves of MLC are moving during irradiation.
- Each pair of composing leaf sweeps across target volumes under computer control.

Dynamic IMRT



- Faster than Static IMRT
- Smooth intensity modulation acheived
- Beam remains on throughout – leakage radiation increased
- More susceptible to tumor motion related errors.
- Additional QA required for MLC motion accuracy.

Dr Santam Chakraborty Department of Radiotherapy, PGIMER Chandigarh

- **Deterministic Approaches**
- 1) Fast gradient descent method ---Konrad---T.Bortfeld---1990
- 2) Newton's Method
- 3) Conjugate Gradient method -------Helios---Varian

- **Stochastic methods**
- 1) Simulated Annealing----used in Peacock system------S.Webb
- 2) Genetic Algorithms

- **First MLC based treatment ----MSKCC----1995**

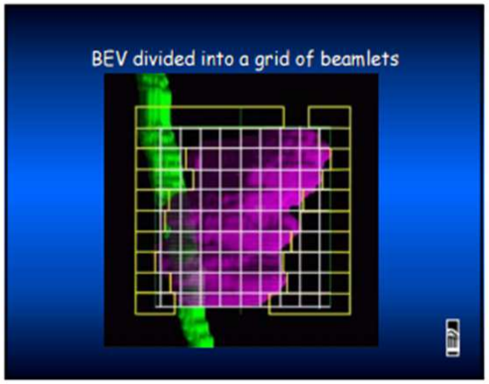
Aperture based IMRT or DMPO

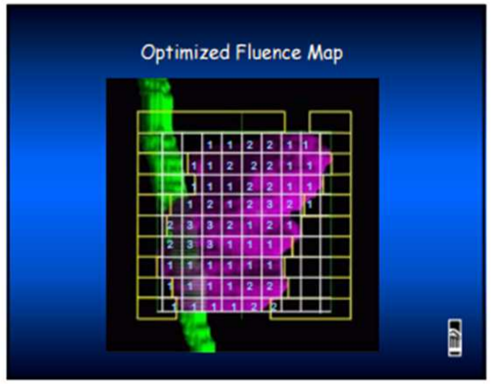
- In some recent inverse planning algorithms the optimization of the intensity maps and the subsequent leaf sequencing step have been abandoned altogether and the MLC segment shapes (apertures) are directly optimized (De Gersem *et al 2001). This approach has been called* direct aperture optimization (Shepard *et al 2002) or direct machine parameter optimization*.

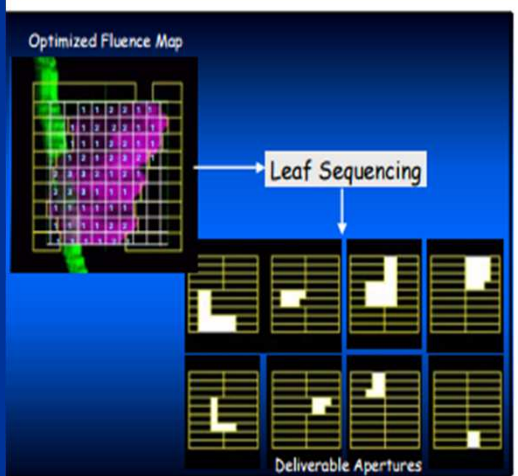
DMPO continued

- The removal of the intensity map optimization as an intermediate step in inverse planning makes the problem much more difficult (non-convex) from a mathematical point of view.

- In spite of this mathematical difficulty, practical direct aperture optimization algorithms have generated excellent IMRT plans with a small number of segments, especially when fed with a good initial guess of the segment shapes.


BEV divided into a grid of beamlets


Optimized Fluence Map


Optimized Fluence Map
Leaf Sequencing
Deliverable Apertures


Beamlet-Based Inverse Planning
• Two-step approach to treatment planning:
1. Fluence map optimization - Delivery constraints ignored
2. Leaf sequencing - Accounts for delivery constraints
• Employed by nearly all commercial vendors:
• Corvus (NOMOS),
• Pinnacle (ADAC),
• Plato (Nucletron),
• Focus (CMS)
• Theraplan (MDS Nordion)

Beamlet-based Inverse Planning

The separation of intensity map optimization and leaf sequencing results in a large number of segments with the following consequences:

1. Inefficient delivery (large # of MUs, long delivery time)
2. Requires extremely high geometric accuracy and intensive QA efforts
3. A dramatic change in practice

Aperture-Based Optimization
A One-step process

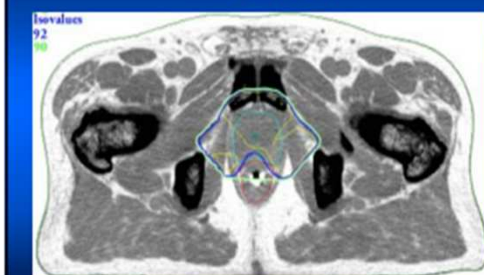
1. Contour-based planning
   - Anatomy contour-based
   - Isodose contour-based
2. Direct Aperture Optimization

Contour-based using anatomy
Prostate Case

PTV   PTV - rectum

Courtesy Thomas Jefferson University

Contour-based using anatomy
Prostate Case



Courtesy Thomas Jefferson University

Advantages

- Aperture shapes are intuitive
- Small number of apertures = quick delivery.
- No leaf-sequencing.
  - No need to recompute dose after optimization.
  - Plan quality does not degrade.

Disadvantages

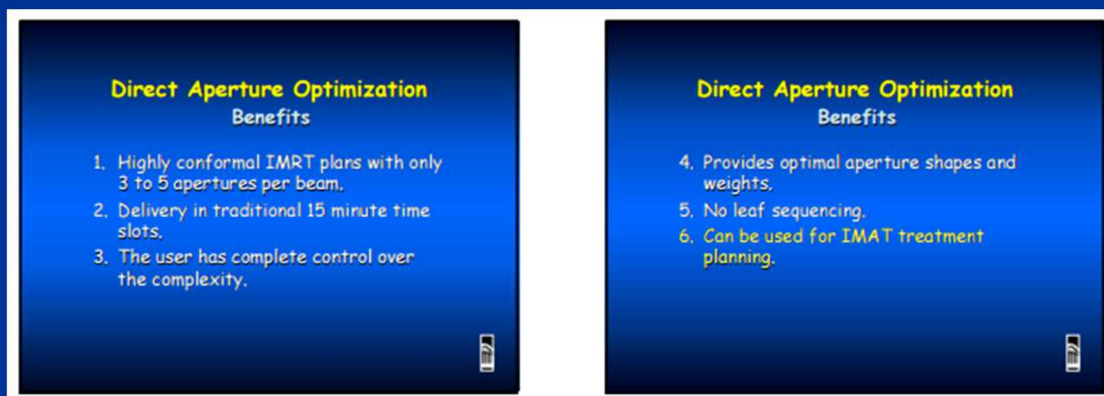
- Difficult to make robust for all target sizes and shapes:
  - typically used in a site specific fashion
- The solution space is limited before optimization.
- Plan quality may not rival that of beamlet-based optimization.

Direct Aperture Optimization (DAO)

1. Inverse planning technique where aperture shapes and weights are optimized simultaneously.
2. All of the MLC delivery constraints are included in the optimization.
3. The number of apertures per beam angle is specified in the prescription.

Optimization via Simulated Annealing

1) Pick a parameter (leaf position, aperture weight) randomly
2) Change the parameter by a random amount
3) Calculate objective function based on the new dose distribution
4) Objective function lower: accept change
5) Objective function higher: accept change with certain probability


Direct Aperture Optimization
Benefits
1. Highly conformal IMRT plans with only 3 to 5 apertures per beam.
2. Delivery in traditional 15 minute time slots.
3. The user has complete control over the complexity.
Direct Aperture Optimization
Benefits
4. Provides optimal aperture shapes and weights.
5. No leaf sequencing.
6. Can be used for IMAT treatment planning.

Delivery Type Dictates Ideal Optimization Type

Delivery Type

Ideal Optimization Type	SMLC (Step and Shoot)	IMAT	DMLC (Dynamic MLC)	Tomotherapy (Binary MLC)
Beamlet	X	X	√	√
Aperture	√	√	X	X

History of VMAT

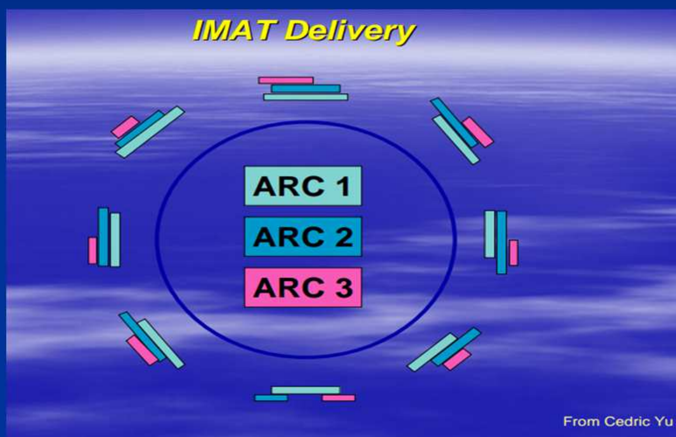
Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy

C X Yu 1995 *Phys. Med. Biol.* **40** 1435-1449 doi:10.1088/0031-9155/40/9/004

- VMAT, formally known as Intensity Modulated Arc Therapy (IMAT), was first brought up by Dr. Cedric Yu in 1995.

Basics of IMAT

- IMAT is a rotational IMRT that can delivered using conventional linear accelerators with conventional MLC.
- Radiation is on while gantry is rotating with MLC leaves moving continuously.
- Intensity modulation is created by overlapping arcs.



Understanding Single Arc

- By using large number (100+) of shape variations, intensity modulation is effectively achieved at the target level.
- It is, therefore, capable of achieving IMRT-like plan quality for simple as well as complex cases.

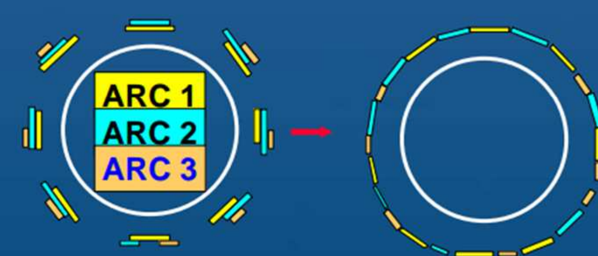
so,

Is it the same as 36 beam IMRT?

In principle: Yes.

In practice: No quite.

This picture ignored deliverability!



Tang et al, Int. J Rad Onc. Biol Phys, 2007

Monaco VMAT Algorithm

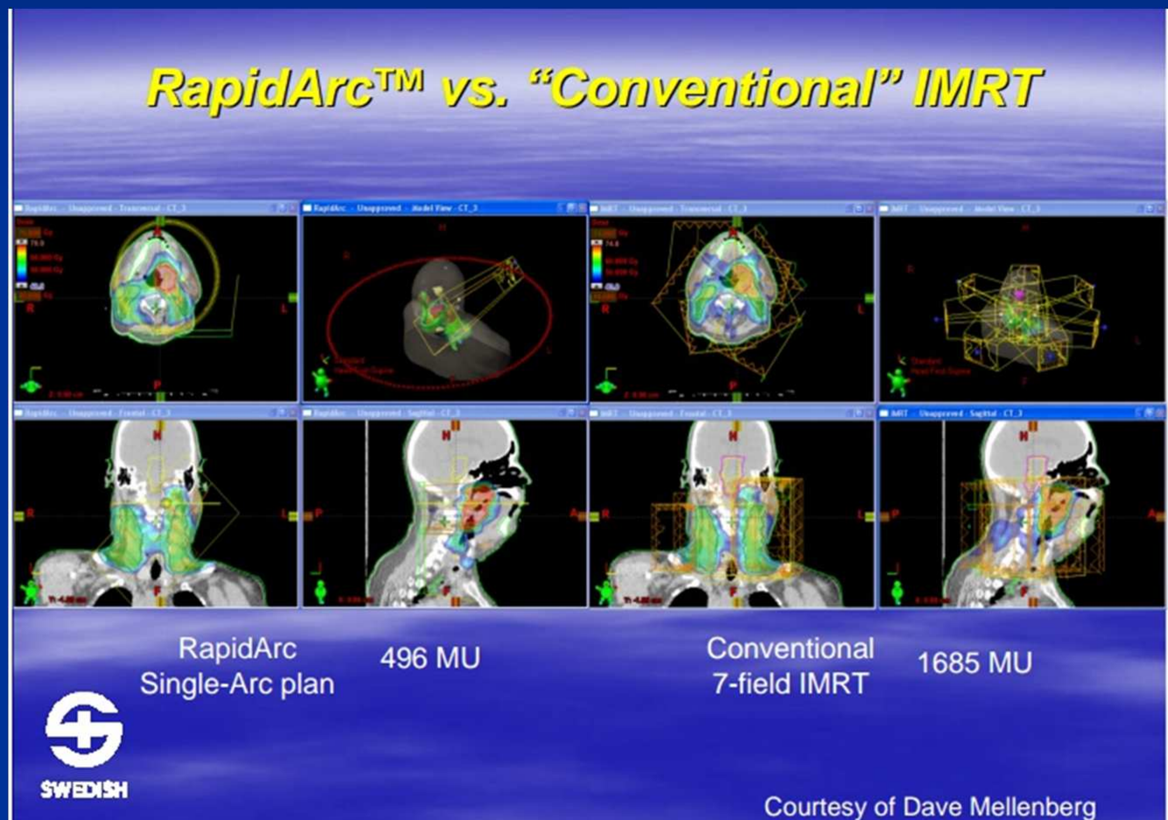
- Optimized fluence maps are produced at a series of discrete beam angles.
- These optimized fluence are then converted into deliverable VMAT arcs.

IMAT to VMAT – New Developments

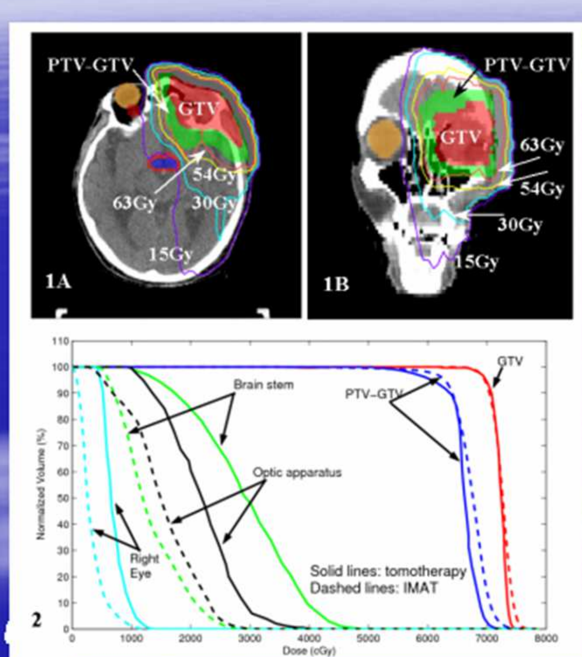
Delivery Control Systems

- Elekta and Varian have introduced new linac control systems that will be able to change the MLC leaf positions and dose rate while the gantry is rotating.
- Elekta → PreciseBeam Infinity®
- Varian → RapidArc®
- Both are using the term Volumetric Modulated Arc Therapy (VMAT).


RapidArc. One revolution is all it takes.
RapidArc always uses single arc to deliver treatment

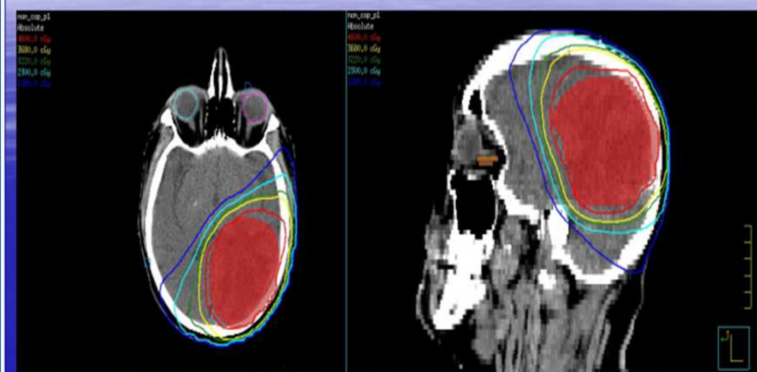

RapidArc™ vs. "Conventional" IMRT
RapidArc
Single-Arc plan
496 MU
Conventional
7-field IMRT
1685 MU
SWEDISH
Courtesy of Dave Mellenberg

An orbit case using sagittal arc



- The prescriptions to GTV and PTV-GTV are 70 and 63 Gy, respectively.
- A VMAT plan with four 210º sagittal arcs were created for this case.

A Brain GBM case

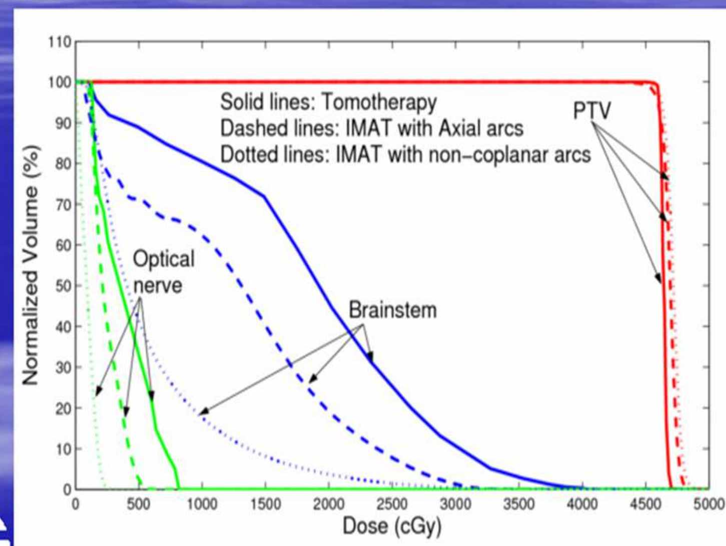


axial sagittal

- Both coplanar and non-coplanar VMAT plans were generated for this case.
- The above isodose plots are from the non-coplanar VMAT plan. Five isodose levels are plotted: 100%, 80%, 70%, 50%, and 30%.

SWEDISH

DVH comparisons for this brain case



SWEDISH

IMAT QA

COMMISSIONING AND QUALITY ASSURANCE OF RAPIDARC RADIOTHERAPY DELIVERY SYSTEM

C. Clifton Ling, Ph.D.,[*,†] Pengpeng Zhang, Ph.D.,[†] Yves Archambault, M.Sc.,[*] Jiri Bocanek, M.Sc.,[*] Grace Tang, M.Phil.,[†] and Thomas LoSasso, Ph.D.[†]

IMAT involves gantry rotation, dMLC, and variable dose rate. Is it less reliable by default?

- Aperture shape change is enslaved to MUs, proven with dMLC IMRT.
- Both dose rate error and gantry speed error only cause angular errors, to which rotational delivery is known to be insensitive.
- Therefore, if a linac can delivery arc and dynamic IMRT, it can delivery IMAT *reliably*. (passing rates)

Univ of Maryland

IMAT QA

- What is more likely to go wrong?
  - MLC positioning accuracy
- If planning system is not from the linac vendor, be careful about large MLC travel and large dose rate variations
- Phantoms: MapCheck embedded phantoms or similar phantoms (fancy ones require more work and not as intuitive). 3%/3mm pass rate: ~95%
- Couch (stiffening bar) attenuation.

Univ of Maryland

IGRT

Starting point….

General definition of IGRT

- Image guided radiation therapy(IGRT) aims at acquiring anatomical information of the patient in the treatment room to make decisions based on this information and hence improving the quality of the treatment.
-

Acta Oncologica, 2008; 47: 1271–1278

informa healthcare

ORIGINAL ARTICLE

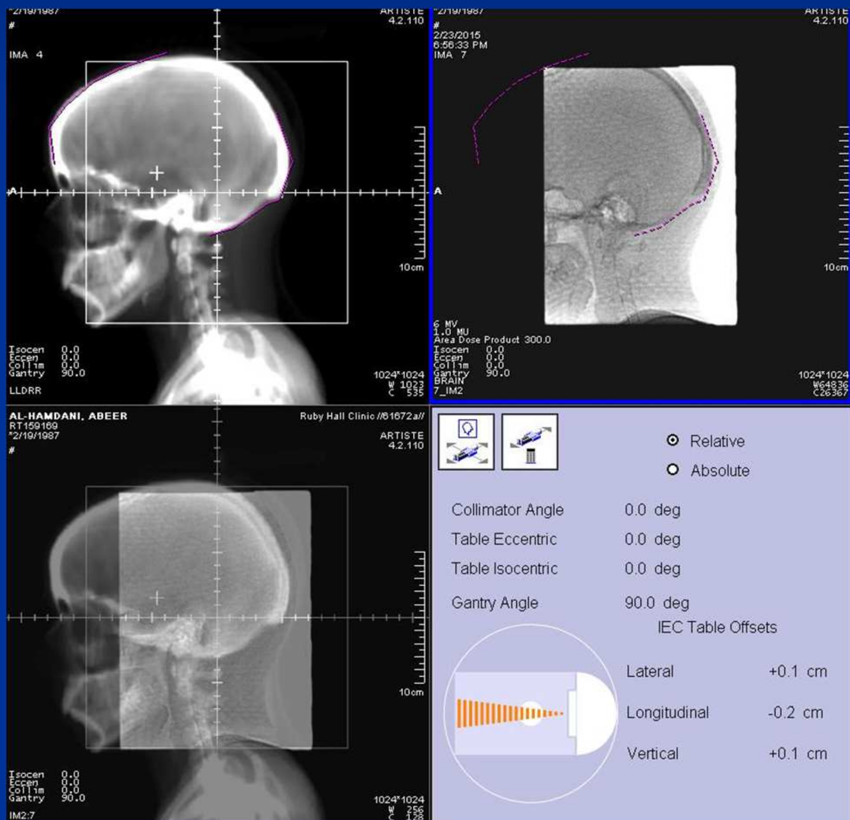
An overview of volumetric imaging technologies and their quality assurance for IGRT

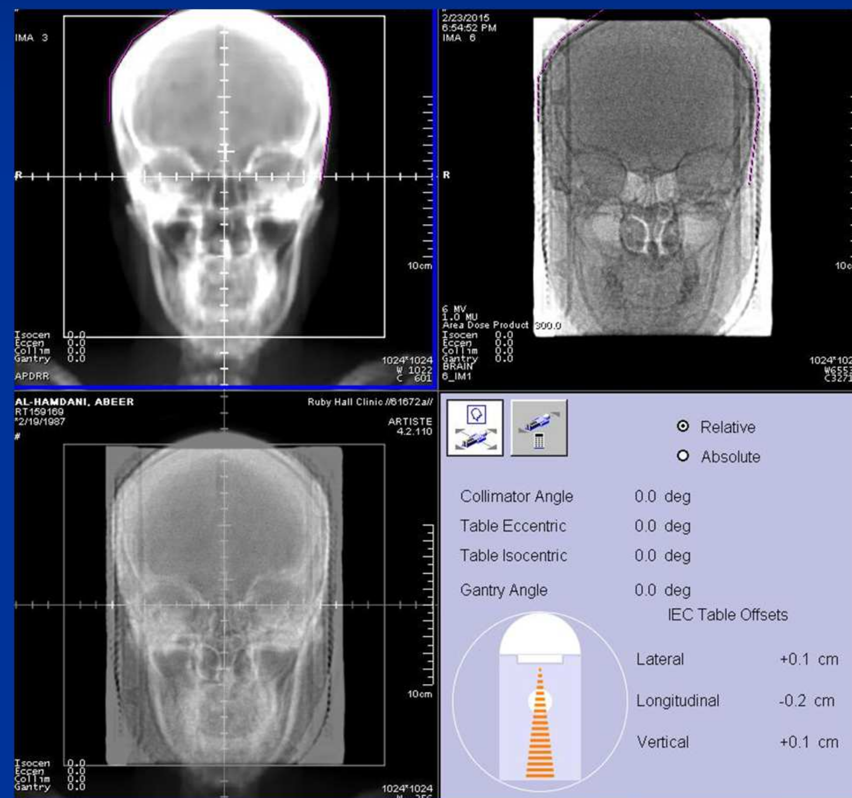
D. VERELLEN, M. DE RIDDER, K. TOURNEL, M. DUCHATEAU, T. REYNDERS, T. GEVAERT, N. LINTHOUT & G. STORME

Systems in use

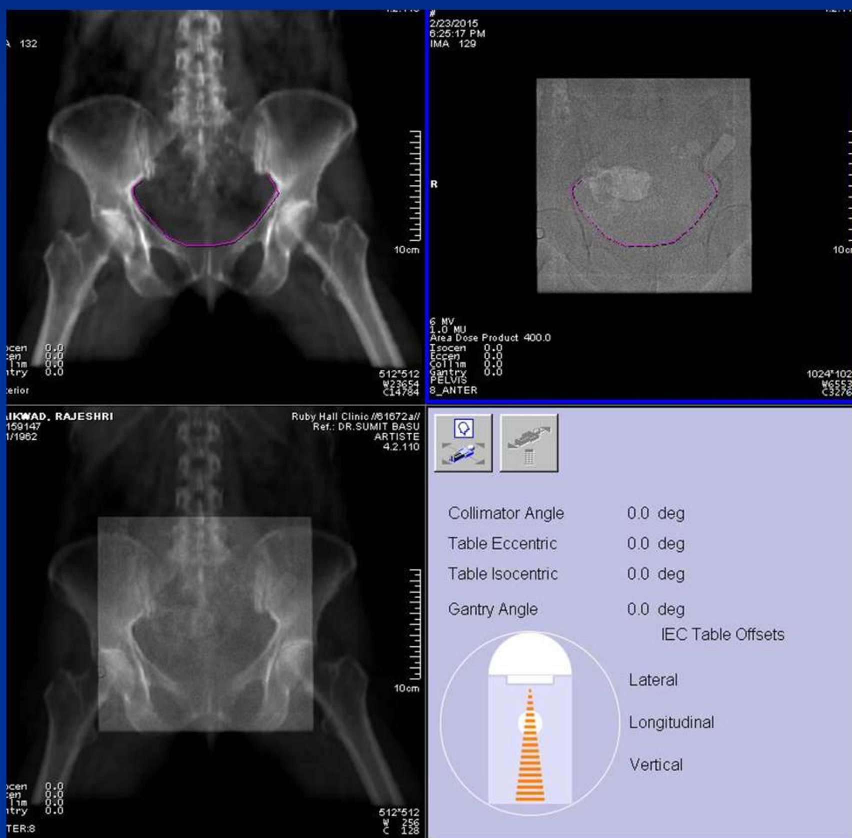
1) Portal Imaging
2) Ultrasound Imaging__BAT
3) 3D IGRT----KV cone beam CT
4) MVCBCT
5) Tomotherapy Imaging
6) 4D real time imaging
7) ExacTrac Imaging
8) Cyberknife Imaging
9) Digital Tomosynthesis(DTS)
10) Clarity
11) MRI Imaging
12) Vero
13) Calypso

Portal Imaging

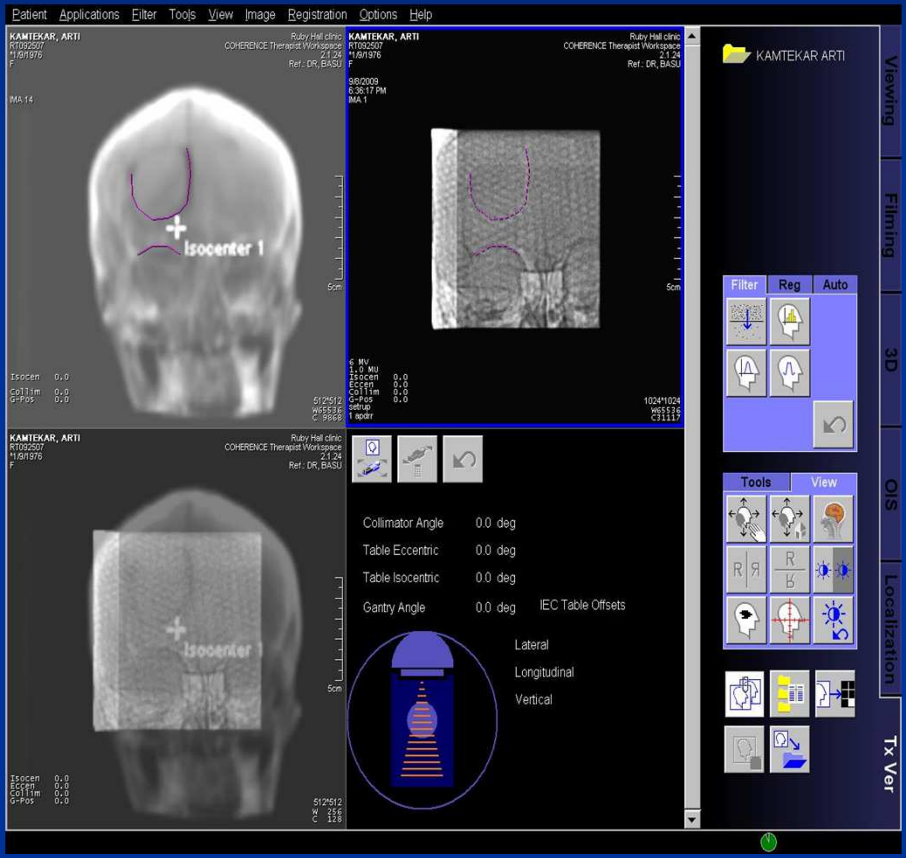


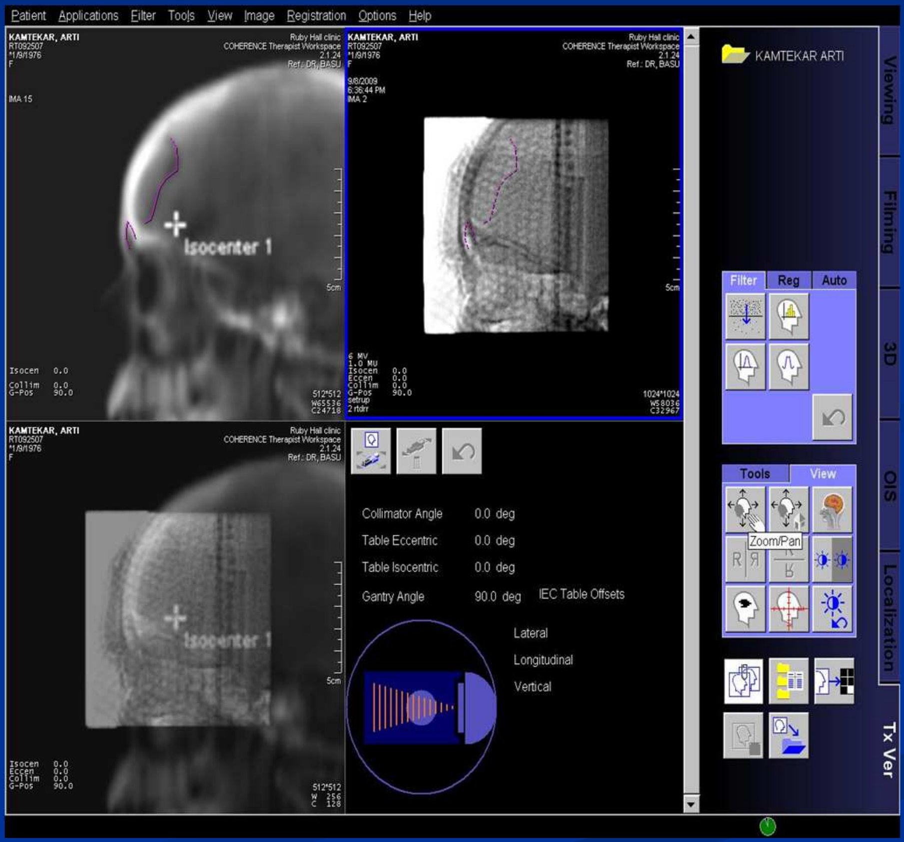


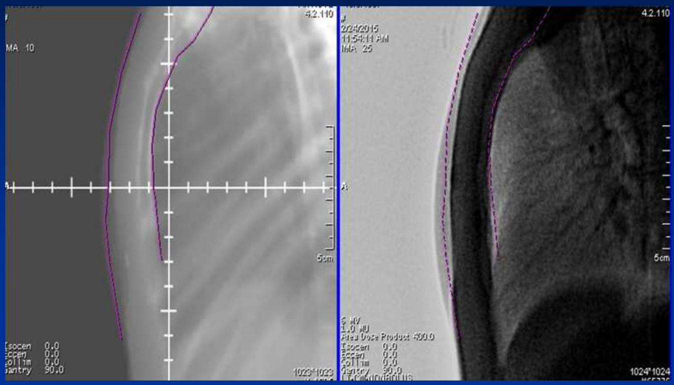
Aligning using Portal Imaging



DRR and portal imaging







- In portal imaging the entire depth characteristics or info is put at 100 cm.
- One marks any definite margin which is 3 dimensional into a 2 dimensional line.

Their relative shifts are given as corrections.
One X and Y from AP and Yand Z from Lat.

Getting to "a point", this is sufficient, but one cannot use it while placing with respect to a volume.

So It is a "verification tool", not a "guiding tool".

Exac Trac

ExacTrac on Varian Linac

ExacTrac on Elekta Linac

- Total Installations:

- India -------- 10
- Worldwide ----700

- FDA approval in 1999.
- (with X-ray tubes?)
- (with 6D couch?)

ExacTrac

- Combining IR camera and kV X-ray imaging systems.
- In the first step, the patient is brought to position by the IR camera system.
- In the second step, the target is accurately located using the kV X-ray imaging system, by comparing the X-ray images with the DRR's obtained from planned CT data set.

A phantom study on the positioning accuracy of the Novalis Body system

Hui Yan,[a] Fang-Fang Yin, and Jae Ho Kim
Department of Radiation Oncology, Henry Ford Hospital, Detroit, Michigan 48202

(Received 30 May 2002; accepted for publication 24 September 2003; published 17 November 2003)

A phantom study was conducted to investigate inherent positioning accuracy of an image-guided patient positioning system—the Novalis Body system for three-dimensional (3-D) conformal radiotherapy. This positioning system consists of two infrared (IR) cameras and one video camera and two kV x-ray imaging devices. The initial patient setup was guided by the IR camera system and

system. The mapping relationship between kV x-ray images and DRRs was established using the following pinhole camera mode:

$$u=\frac{p_{11}x+p_{12}y+p_{13}z+p_{14}}{p_{31}x+p_{32}y+p_{33}z+p_{34}},$$

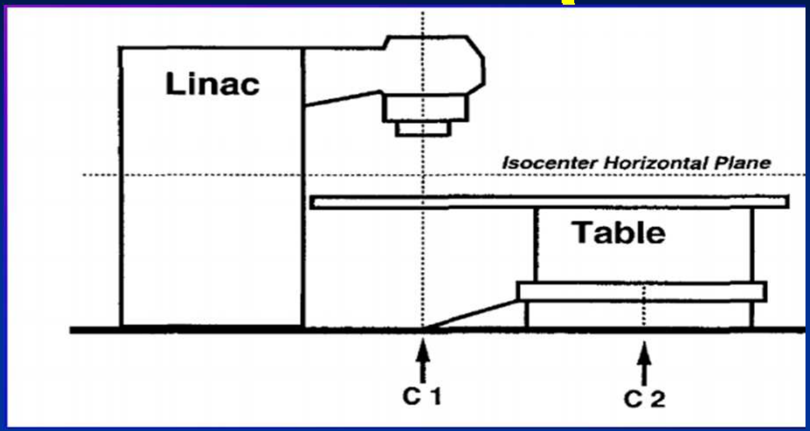
$$v=\frac{p_{21}x+p_{22}y+p_{23}z+p_{24}}{p_{31}x+p_{32}y+p_{33}z+p_{34}}. \quad (1)$$

In this model, (x,y,z) are the 3-D coordinates of a point in the imaging object. (u,v) are the 2-D coordinates of its projection on the kV x-ray images. P_{ij} are unknown project parameters, which was determined by calibrating a Novalis Body phantom with two sets of markers attached. As shown

MP.2003. 30(12) pp3052-60

- Robust algorithm. Less time consuming.
- Automatic corrections.
- First to introduce 6D couch.
- Needs a watch on its calibration including the couch rotations.
- Use of implanted markers is highly recommended.
- Criticism--- It is only planar images.
- Does not allow you to see the relative anatomy as 3D imaging promises.
- Has a learning curve.
- Users of ExacTrac and Cone beam imaging, slowly tend to perform less cone beam.

Concept of CT on Rails.



C2 is the Column Axis.

Int. J. Radiation Oncology Biol. Phys., Vol. 35, No. 3, pp. 587-592, 1996

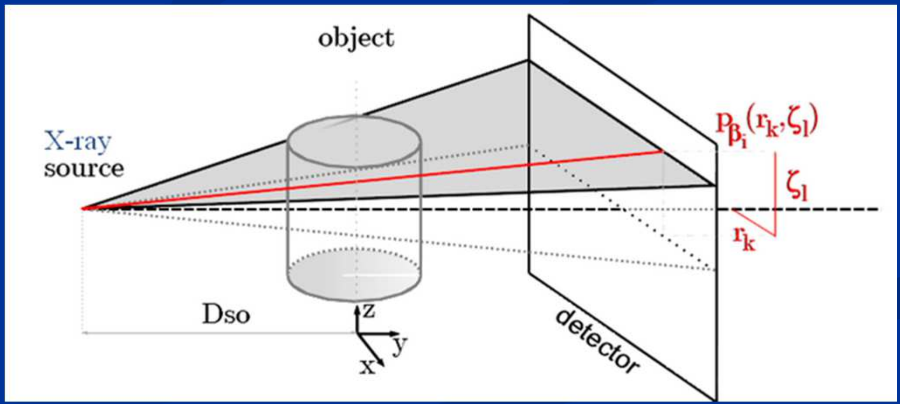
Column 0°

Column=180°

Cone Beam CT

The algorithm of Feldkamp, Davis, and Kress [J. Opt. Soc. Am. A 1, 612-619 (1984)] is a widely used filtered-backprojection algorithm for three-dimensional image reconstruction from **cone-beam** (CB) projections measured with a circular orbit of the x-ray source.

A diverging cone of radiation beam rotating around an object and the transmitted data being reconstructed to form a volume data set is called Cone beam CT.



Feldkemp backprojection algorithm

FBP Deficiencies

- Difficulty in motion correction.
- Lack of flexibility.
- Not being able to model the noise and therefore more radiation.
- FBP assumes monochromatic source, but in reality we have polychromatic X-rays.
  - When polychromatic X-ray beam passes through matter, low energy photons are absorbed.
  - The beam gradually becomes harder, i.e. X-rays in ranges that are more penetrating are referred to as *hard*, opposed to *soft* X-rays that are more easily attenuated.
  - If not corrected, this may cause artifacts in CT images, as a result of inaccurate measurements.

This phenomenon is called Beam Hardening.

The first KV volumetric article from Elekta group

Int. J. Radiation Oncology Biol. Phys., Vol. 53, No. 5, pp. 1337–1349, 2002

0360-3016/02/$–see front matter

ELSEVIER

PII S0360-3016(02)02884-5

PHYSICS CONTRIBUTION

FLAT-PANEL CONE-BEAM COMPUTED TOMOGRAPHY FOR IMAGE-GUIDED RADIATION THERAPY

David A. Jaffray, Ph.D., Jeffrey H. Siewerdsen, Ph.D.,* John W. Wong, Ph.D., and Alvaro A. Martinez, M.D.

Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, MI

Purpose: Geometric uncertainties in the process of radiation planning and delivery constrain dose escalation and induce normal tissue complications. An imaging system has been developed to generate high-resolution, soft-tissue images of the patient at the time of treatment for the purpose of guiding therapy and reducing such uncertainties. The performance of the imaging system is evaluated and the application to image-guided radiation therapy is discussed.
Methods and Materials: A kilovoltage imaging system capable of radiography, fluoroscopy, and cone-beam computed tomography (CT) has been integrated with a medical linear accelerator. Kilovoltage X-rays are generated by a conventional X-ray tube mounted on a retractable arm at 90° to the treatment source. A 41 × 41 cm^2 flat-panel X-ray detector is mounted opposite the kV tube. The entire imaging system operates under computer control, with a single application providing calibration, image acquisition, processing, and cone-beam CT reconstruction. Cone-beam CT imaging involves acquiring multiple kV radiographs as the gantry rotates through 360° of rotation. A filtered back-projection algorithm is employed to reconstruct the volumetric images. Geometric nonidealities in the rotation of the gantry system are measured and corrected during reconstruction. Qualitative evaluation of imaging performance is performed using an anthropomorphic head phantom and a coronal contrast phantom. The influence of geometric nonidealities is examined.
Results: Images of the head phantom were acquired and illustrate the submillimeter spatial resolution that is

Red Vol 53.No.5 pp1337-1349, 2002

More than 1000 citations

First CBCT article

Jaffray, D., Siewerdsen, J., Wong, J. et al, Flat-panel conebeam computed tomography for image-guided radiation therapy, Int. J. Radiat. Oncol. Biol. Phys., 53 (5): 1337-1349, 2002

Williwam Beaumont Hospital, Royal Oak, MI,USA

Some parameters of the XVI

- Focal spot detector distance—155 cm
- Cone angle-----15°
- Voxel dimensions(nominal)—(0.025x0.025x0.025)cm3

Cone-Beam CT Acquisition Parameters	
Tube potential	120 kVp
Tube current	25 mA
Exposure time	25 ms
Number of exposures (nominal)	330
Total mAs for CBCT acquisition	206 mAs
Tube output (mR/mAs in air at isocenter)	5.7 mR/mAs
Total exposure (mR in air at isocenter)	1.2 R
Angular range of projection views	360°
Average angular velocity of gantry	(2.0 ± 0.2) °/s
Average angular increment	$(1.1 \pm 0.3)°$
Detector readout interval (frame time)	570 ms
Time for CBCT acquisition	188 s

XVI

- Mounted at 90° to the treating beam
- Uses 40-130 KV
- Uses a fixed SID
- Can be made to a full FOV by combing two scans of 180°.
- Need to pull and push the detector manually.
- Produces huge artifacts for dental fillings, Hip prosthesis and orthopaedic hardware.

QA Phantom

Daily Simultaneous QA Testing

Used by a therapist every morning, testing takes little or no extra time and can be completed during normal daily equipment warm-up procedures. Ideally, QUASAR™ Penta-Guide Phantom should be used per linac allowing simultaneous system testing and preventing unnecessary start-up delays.

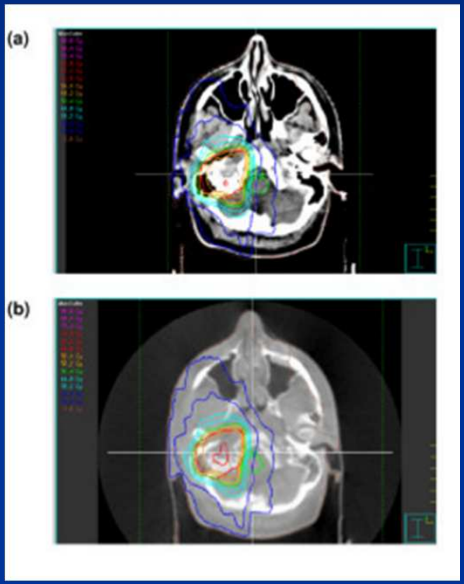
Key Features

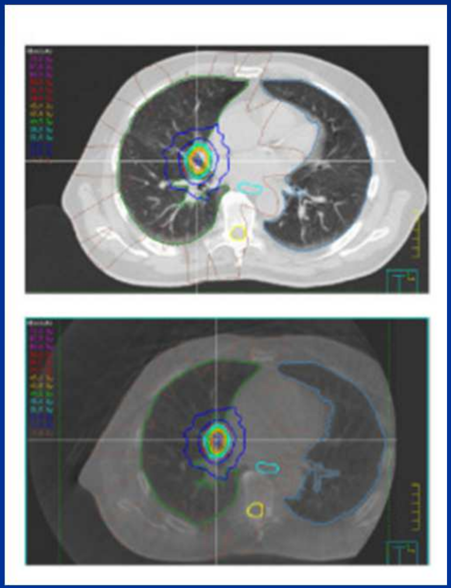
- Enables daily testing to ensure on-board imaging targeting accuracy
- Contains low-density rings and hollow spheres to minimize high-density artifacts
- Includes FREE image analysis software to simplify CBCT QA testing
- Apply simple Pass / Fail acceptance criteria
- Testing does not infringe upon patient treatment time
- Light field alignment 4x4; 10x10; 12x12
- 16 cm cube -5kg
- 1/4 mm accuracy

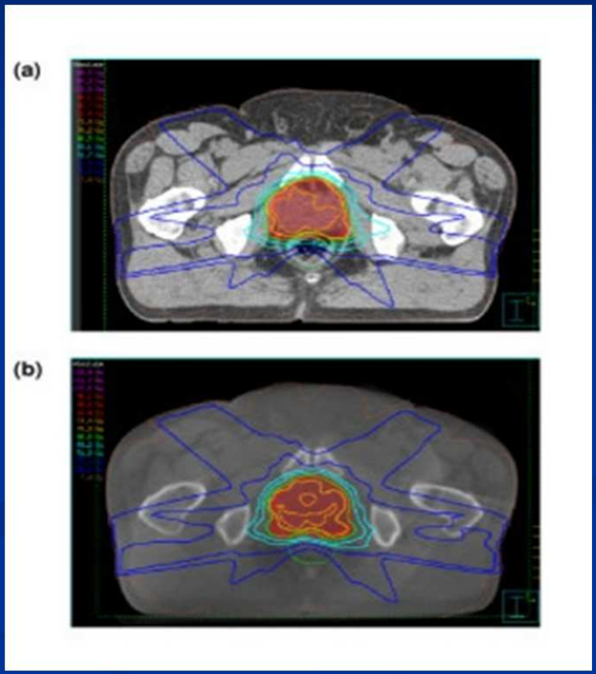
In kV Cone beams, the SPR can be as high as 200%, while imaging a huge volume such as pelvis.

Computations : 5 x 10^9 for 256 x 256 x 256

Richter et al RO 2008.





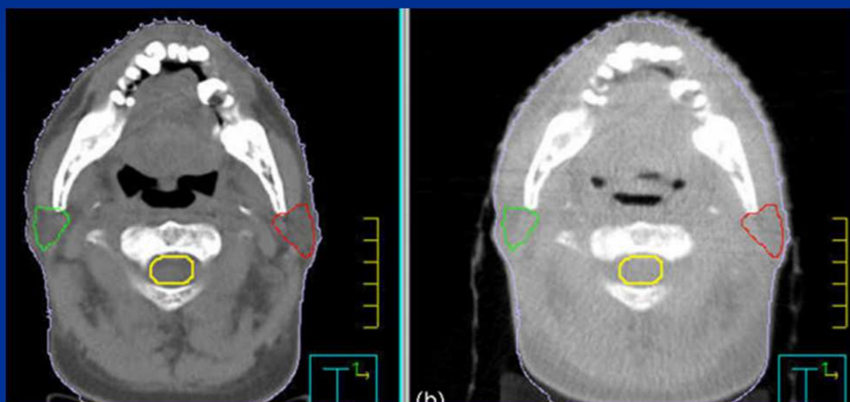


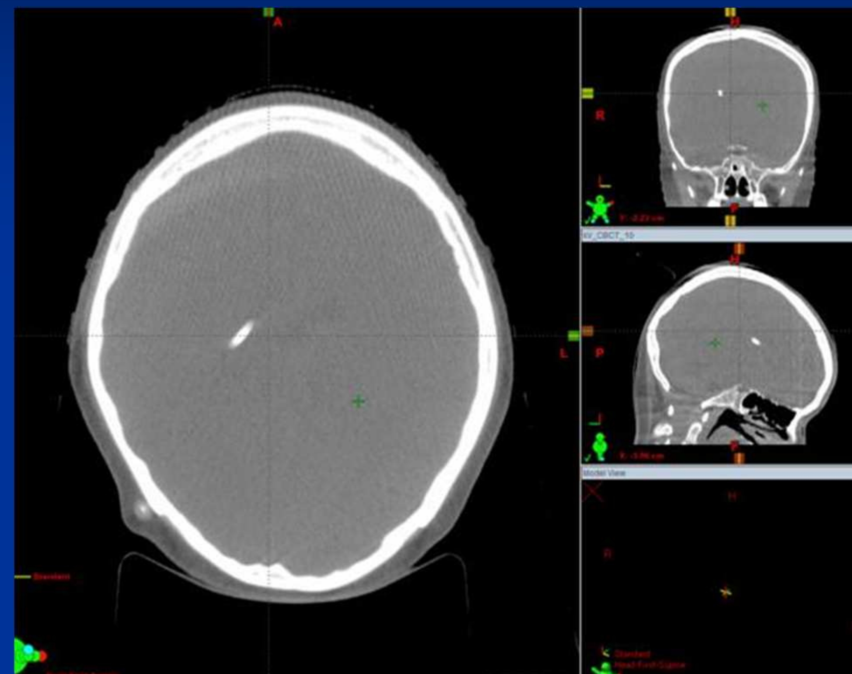
Higher SPR leads to higher inaccuracies in the CT number.

OBI

Uses 60-140 KV
Flexible SID
Uses more projections(700-800) than XVI
Slightly more doses than XVI
Introduced a year later than XVI
Produces huge artifacts for dental fillings, Hip prosthesis and orthopaedic hardware.

OBI images





Hu et al Radiation Oncology 2010.

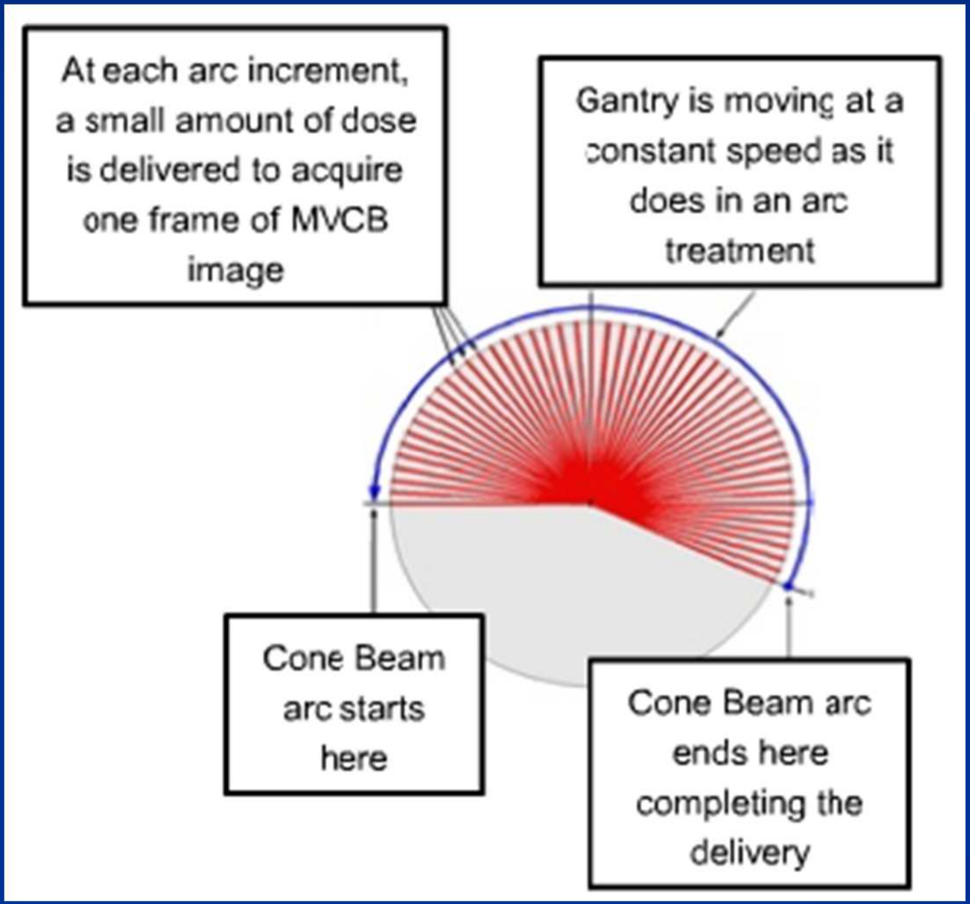
Images with a shunt visible from a True Beam.
Courtesy: Dr.K.R.Muralidhar, American Oncology, Hyderabad.

MVCBCT

Uses the treatment beam.
There is no need of extra hardware
Cost wise sensitive.
Can produce an image of 27cm cylinder(*Oncor*)
Can produce 40cm for *Artiste*.

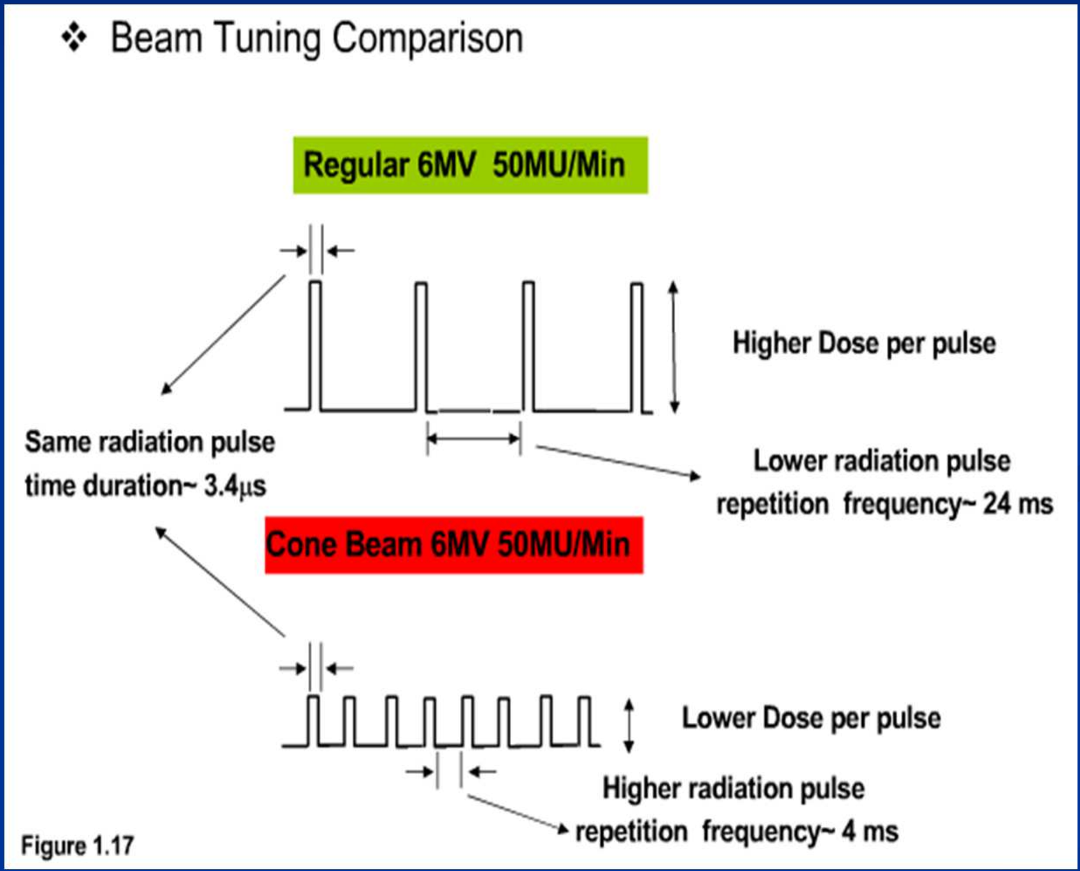
Requires only 200° rotation.
Uses Compton effect predominantly.
Dental implants, Hip prosthesis does not throw huge artifacts.
Resolving low contrast areas require very high doses(Soft Tissue)
Dose to the patient can be 3 to 4 times KvCBCT.

Cone beam arc angle



The Cone beam exposure starts at 270 degree and ends at 110 degree. That is, it rotates 200 degree clockwise giving one exposure per degree.

Beam Tune up for CB

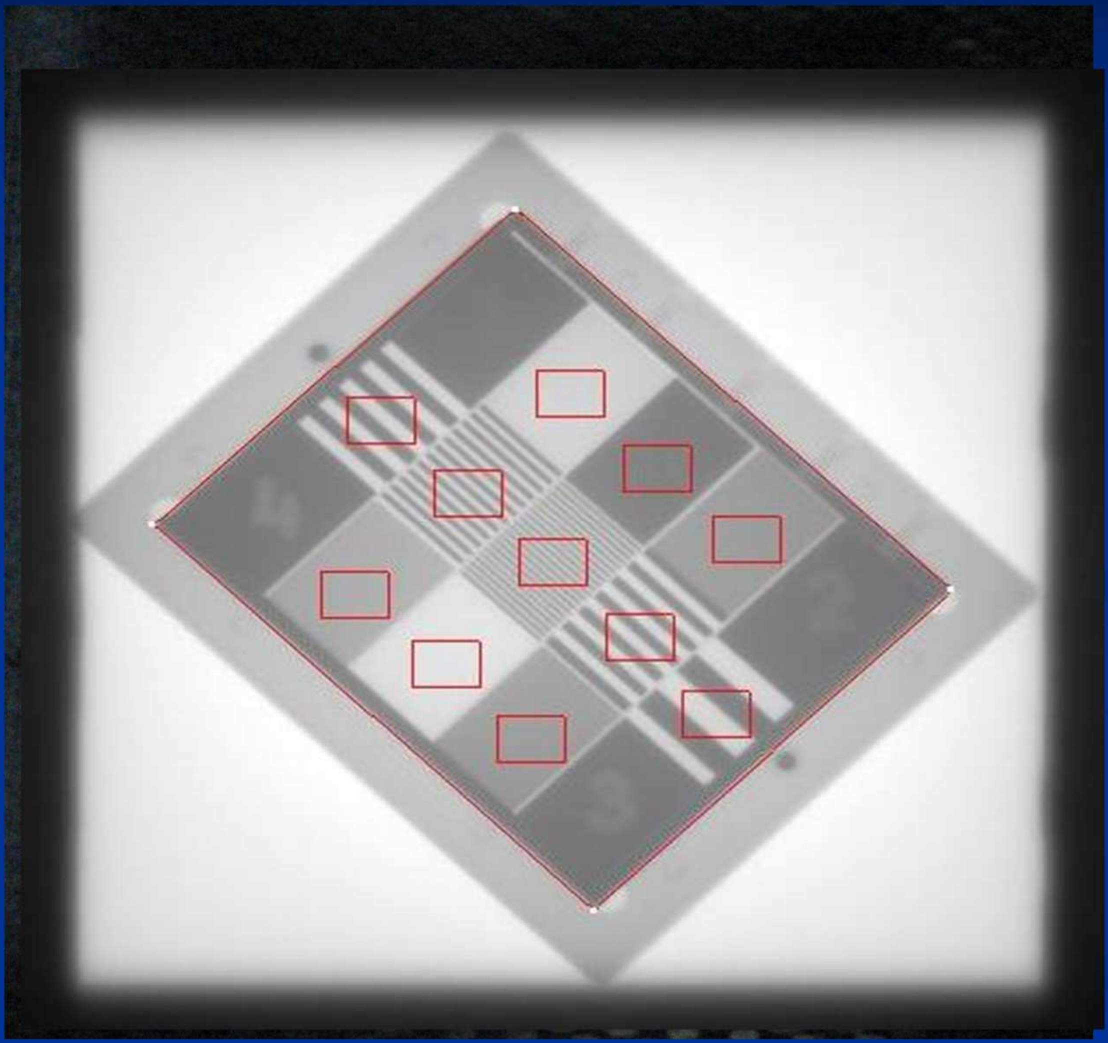


The 50 MU/Min module is used for this purpose. The amplitude of the gun pulse is reduced to one tenth of its initial value. But, the resonance is maintained by increasing the gun pulse to 250pps.

Beam Information

- Reduced beam load makes improved beam formation
- Increased PRF improves the granularity (more stable beam)
- Low dose per pulse (about 0.0033 MU)
- Dose per pulse is reduced approximately 10% of normal
- Repetition rate is adjusted to 250 pps

Phantom Images



Level-2: Contrast & Resolution

Done in the beginning.

Time to perform: 10 minutes.

Resolution: 0.41lp/mm.

The software automatically finds the resolution

The dose at the entrance surface of the arc reach about 160% of the isocenter dose for an imaged pelvis and 133% for the head and neck region.

The dose at the exit surface falls to about 66% of the isocentre dose for a pelvis and 55% for the head and neck region.

J.Chen et al British Journal of Radiology 79(2006) 587-598.

- **MV Cone beam CT**
- --------- Somewhat low in contrast
- ---------- Markers are a must for soft tissue alignment
- ---------- Sub MM markers will not be visible
- ----------High in dose to patients
- Adv -------It is inline and has the single ISO
- --------Lower SPR(50%) leads lower inaccuracy in CT no.
- **KV Cone beam CT**
- Adv--------- High in contrast in comparison
- ----------- Markers are preferred for aligning soft tissue
- ------------ Sub MM markers are also visible.
- ----------- Very low doses to patient
- ----------- One more ISO is defined for QA.

Artefacts……

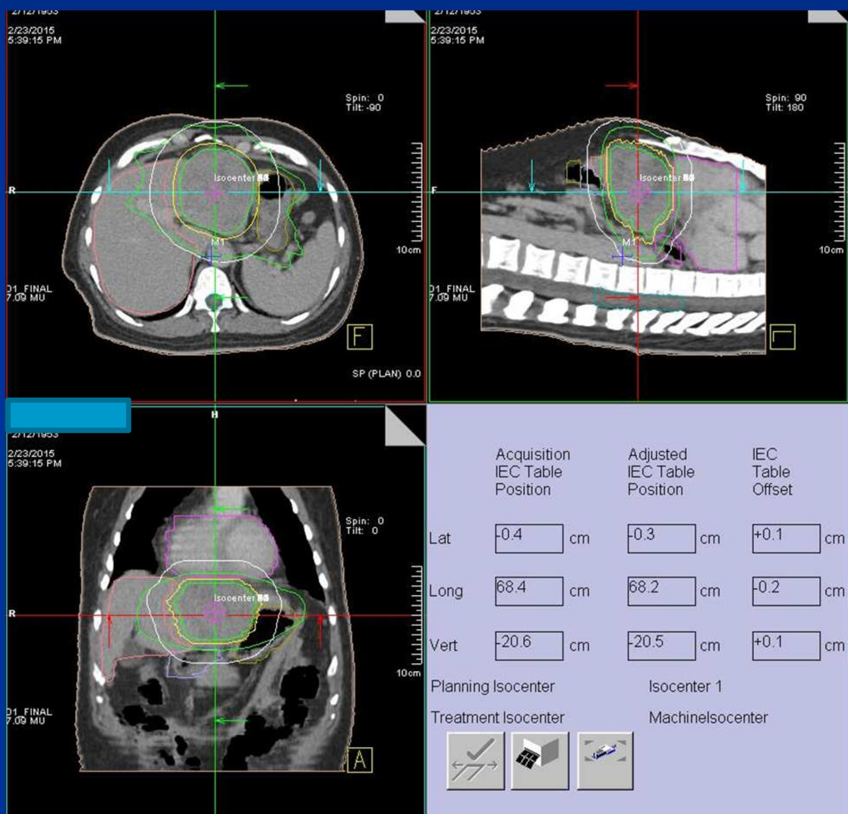
- Discrepancy between actual physical conditions of the measuring set up and the simplified mathematical assumptions used for 3D reconstruction.
- Extinction artefacts
- Aliasing aretefacts
- Ring artefatcs
- Motion artefacts
- Cupping artefatcs

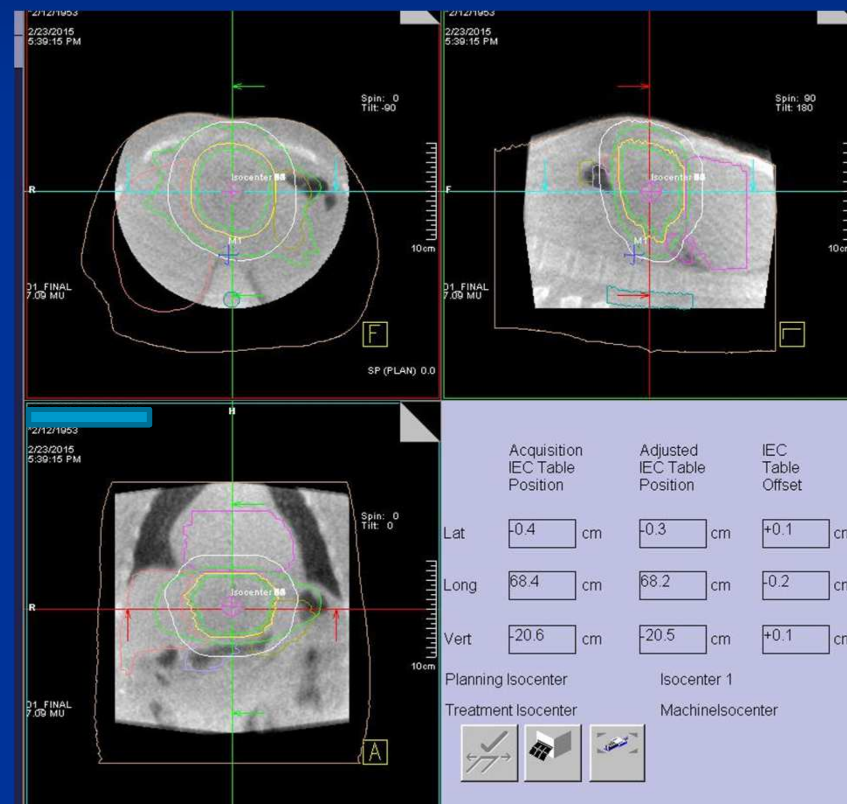
Apart from
Noise and Scatter

CBCT patient workflow

- Select / Load Patient
- Extend imaging gear
- Select imaging parameters
- Bring gantry in start position
- Fire kV while moving gantry
- Reconstruct CBCT
- Align CBCT with reference
- Adjust patient position / shift
- Record shifts
- Retract imaging gear (opt)
- Treat

Courtesy: Jorg Lehman


2/23/2015
5:39:15 PM
Spin: 0
Tilt: -90
Spin: 90
Tilt: 180
Spin: 0
Tilt: 0
Isocenter
10cm
SP (PLAN) 0.0
Acquisition IEC Table Position
Adjusted IEC Table Position
IEC Table Offset
Lat -0.4 cm -0.3 cm +0.1 cm
Long 68.4 cm 68.2 cm -0.2 cm
Vert -20.6 cm -20.5 cm +0.1 cm
Planning Isocenter
Isocenter 1
Treatment Isocenter
MachineIsocenter


2/23/2015
5:39:15 PM
Spin: 0
Tilt: -90
Spin: 90
Tilt: 180
Spin: 0
Tilt: 0
Isocenter
10cm
SP (PLAN) 0.0
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Lat -0.4 cm -0.3 cm +0.1 cm
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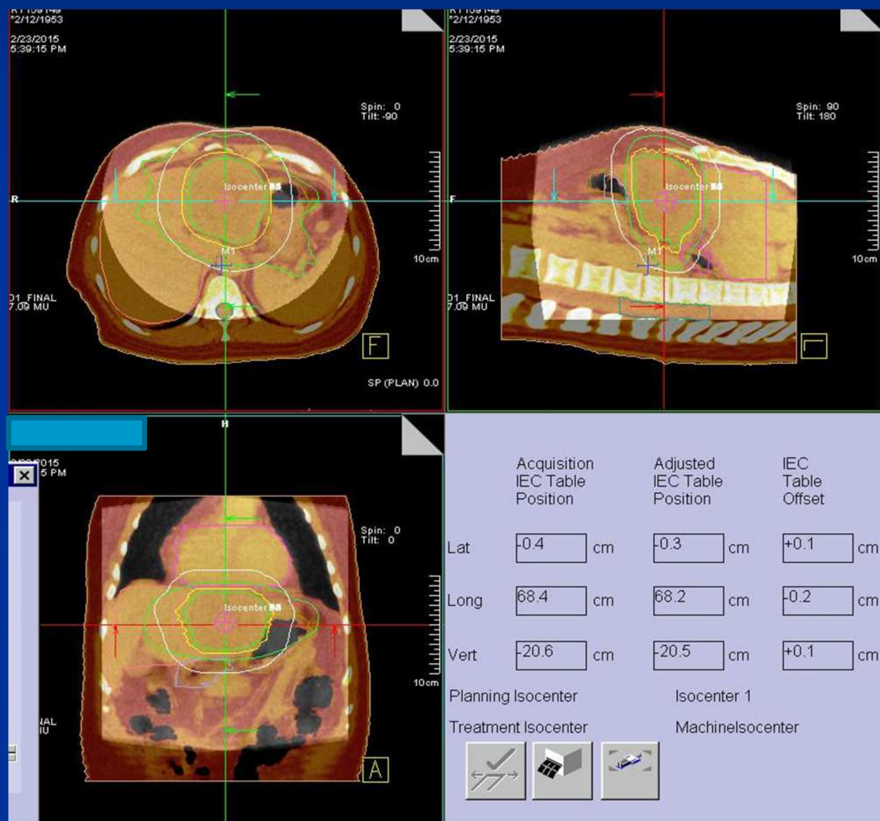
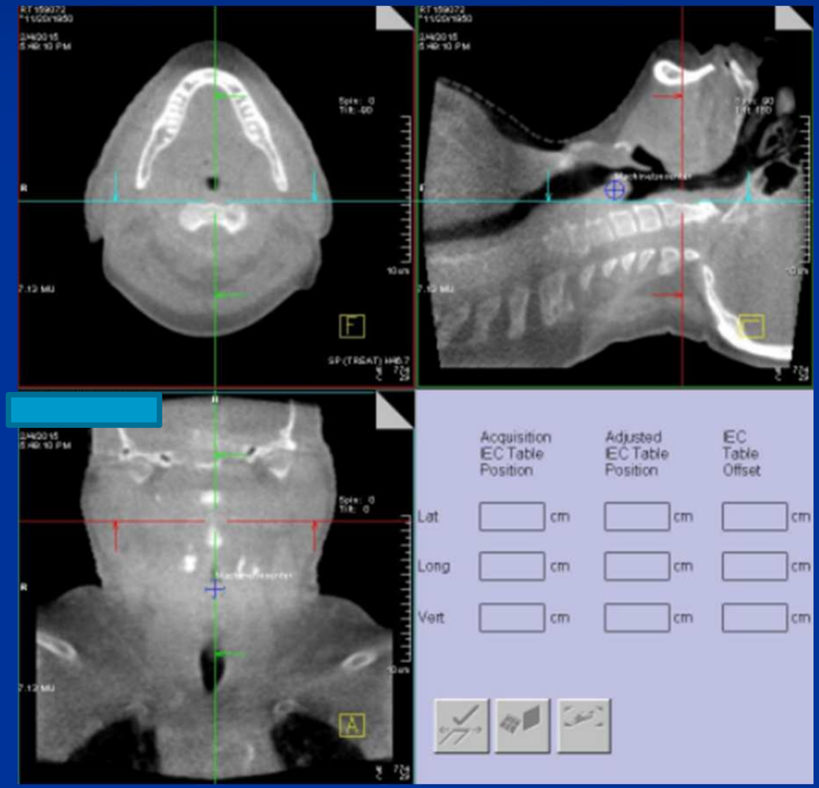
Vert -20.6 cm -20.5 cm +0.1 cm
Planning Isocenter
Isocenter 1
Treatment Isocenter
MachineIsocenter



The arrived at shifts of the table are applied from outside.

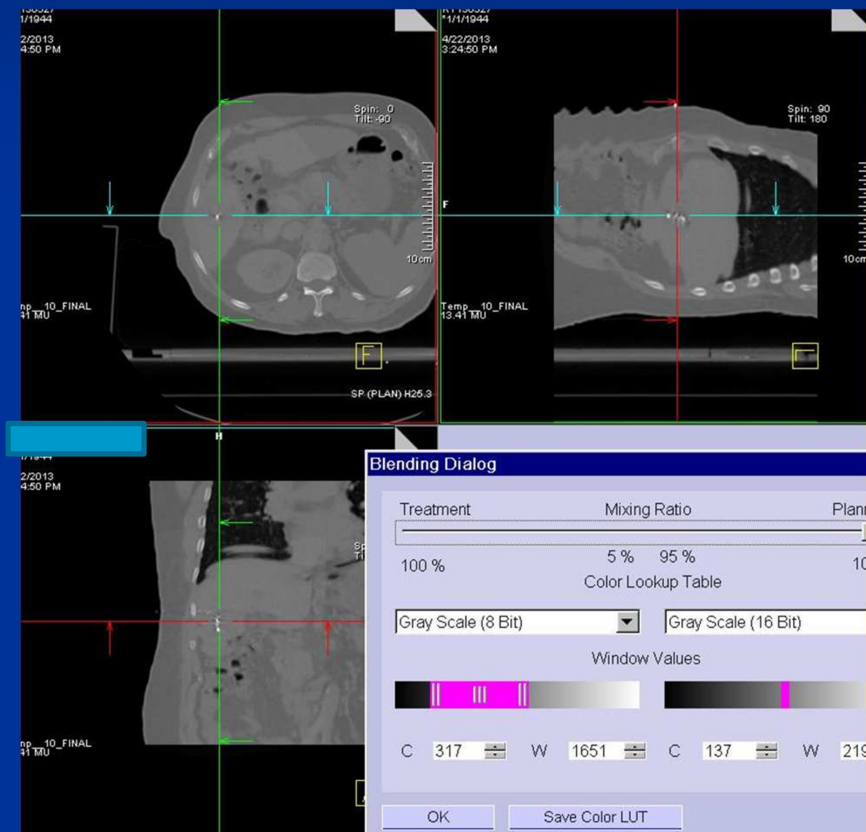
6D couch rotation would help in correcting rotations, but increase the QA load.

Carbon Target Imaging(Kview)

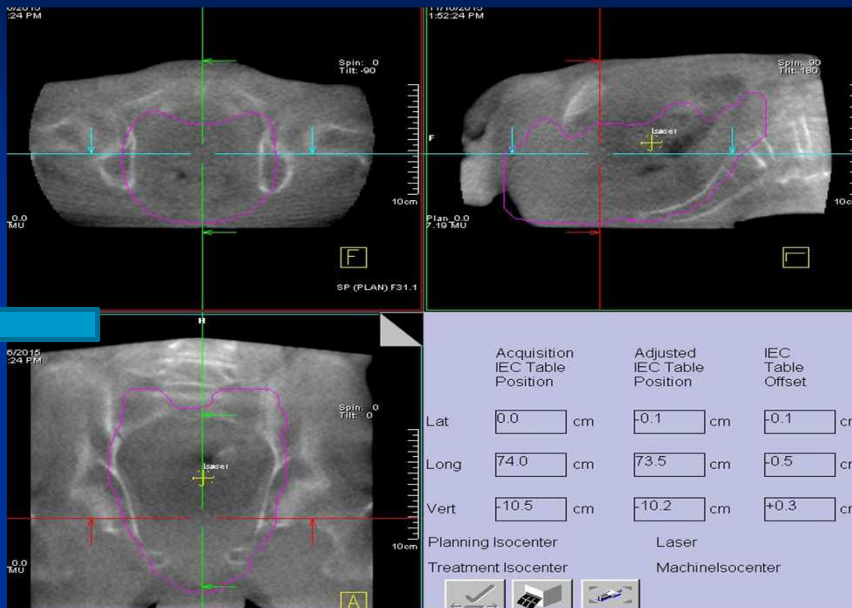


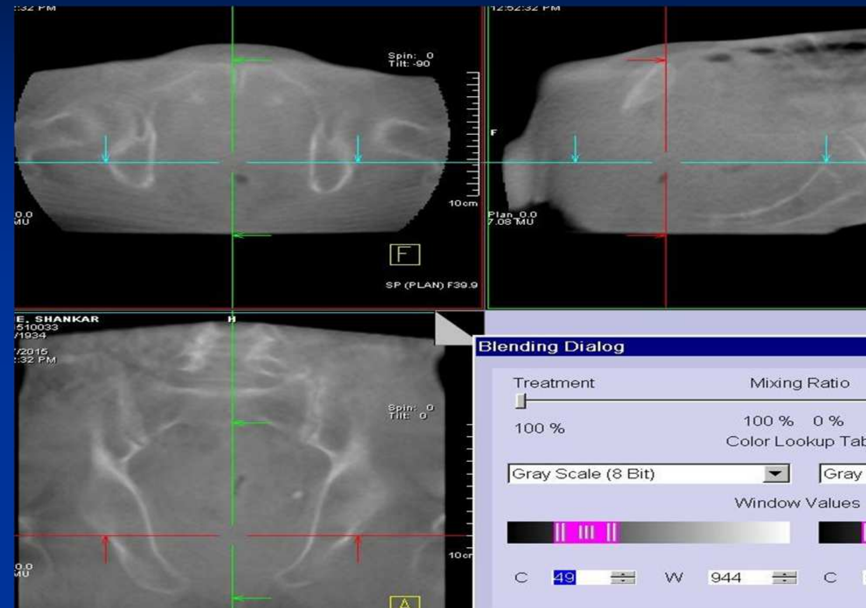
- Uses Carbon target mounted at the electron scaterring foil.
- Unflat beam of energy 4.2 MV is used.
- Soft tissue contrast is 3 times more than MVCBCT.
- Spatial resolution increases to a factor of 2.
- MP.35(12), Dec 2008, 5777-5786

Thin gold markers not being visible in Kview images



Images from MVCBCT,Kview and KVCBCT—Same patient

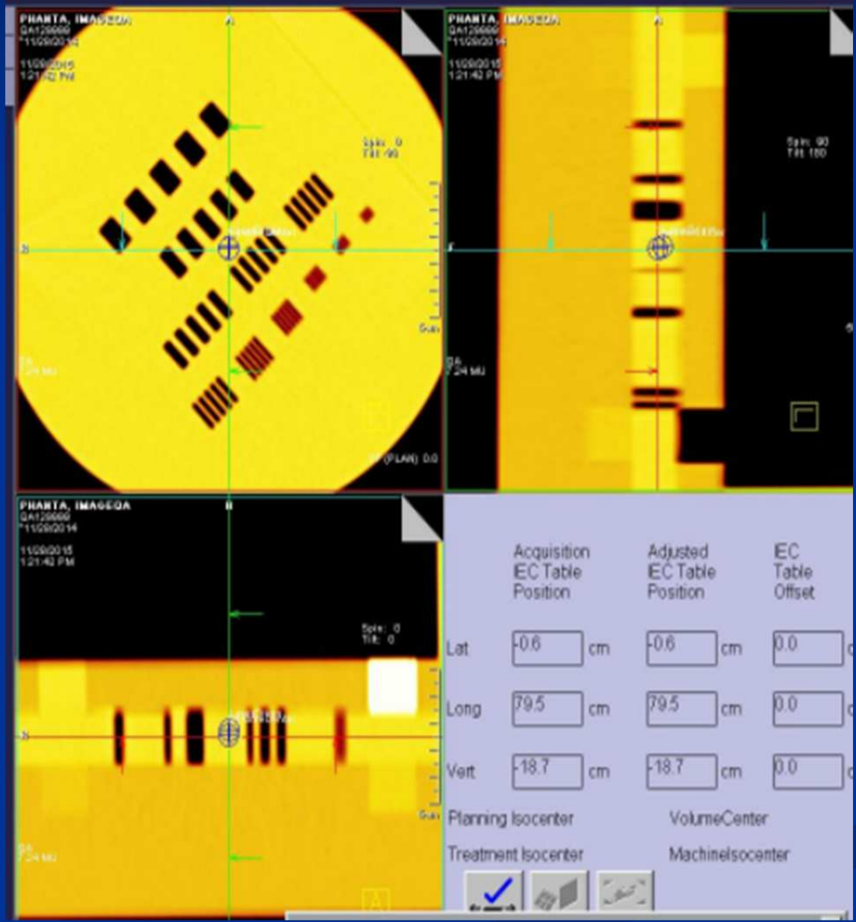




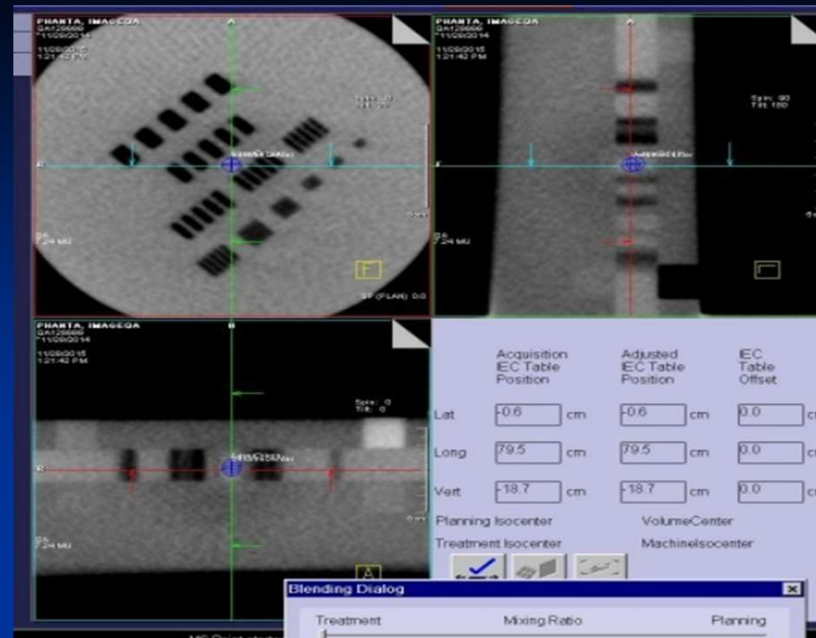
KVCBCT

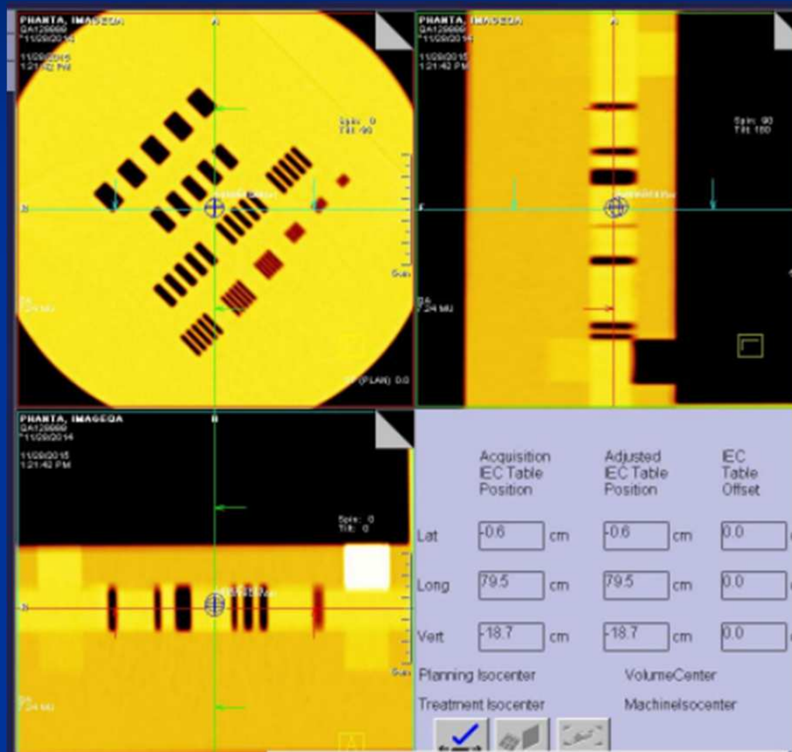
Courtesy: Dr.Goutham Sharon and Mr.Prashant Shinde. Inlaks Hospital, Pune

Geometry Phantom



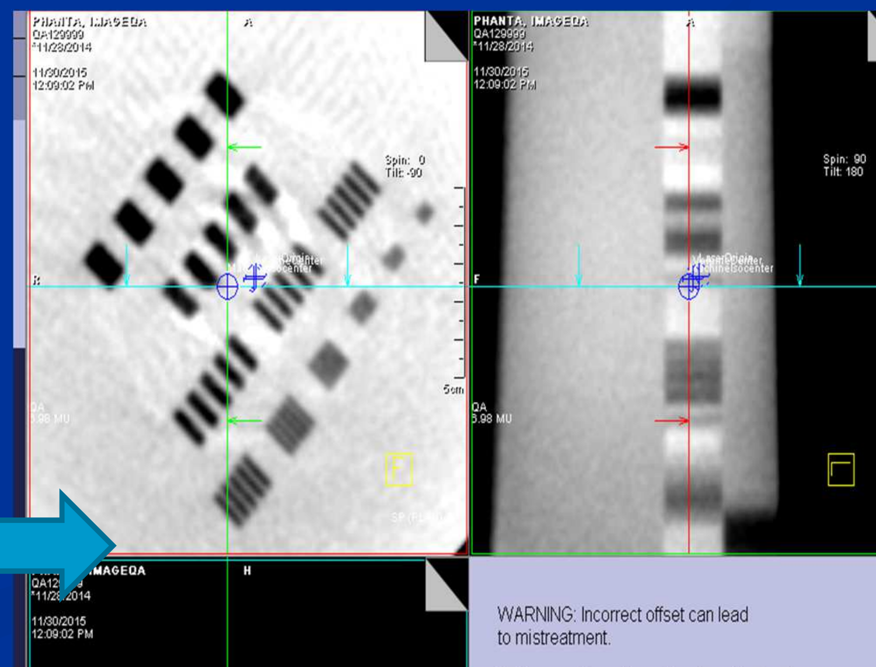
MVCBCT



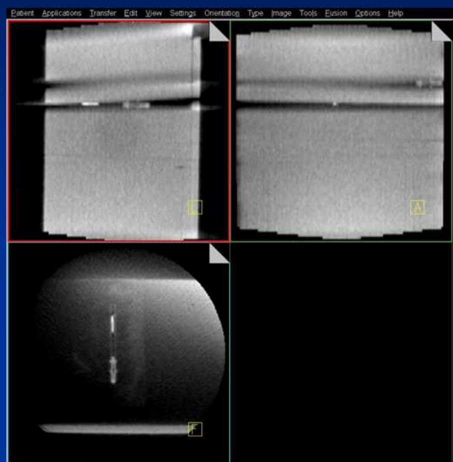


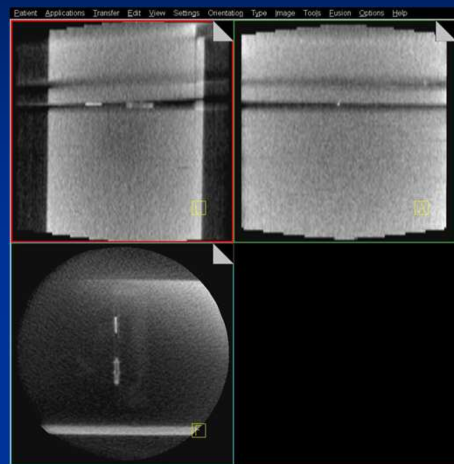
CT image

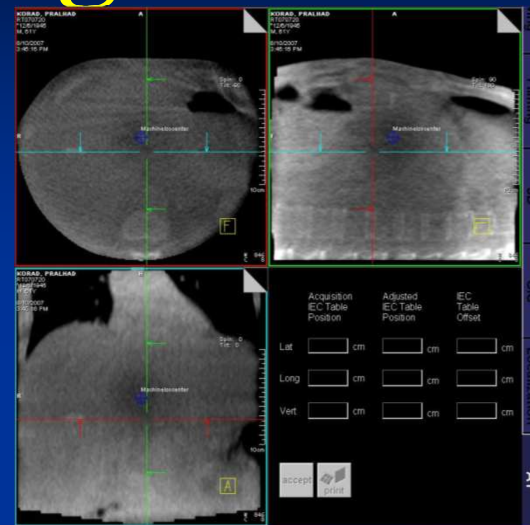
Carbon Target

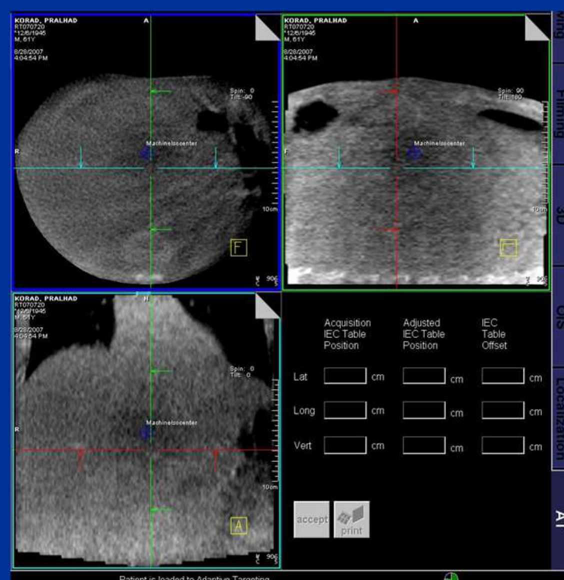


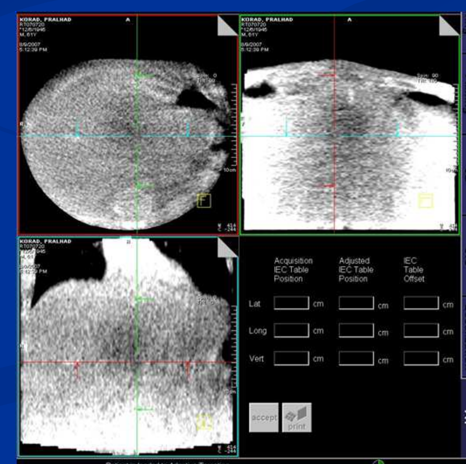
Visicoil Images



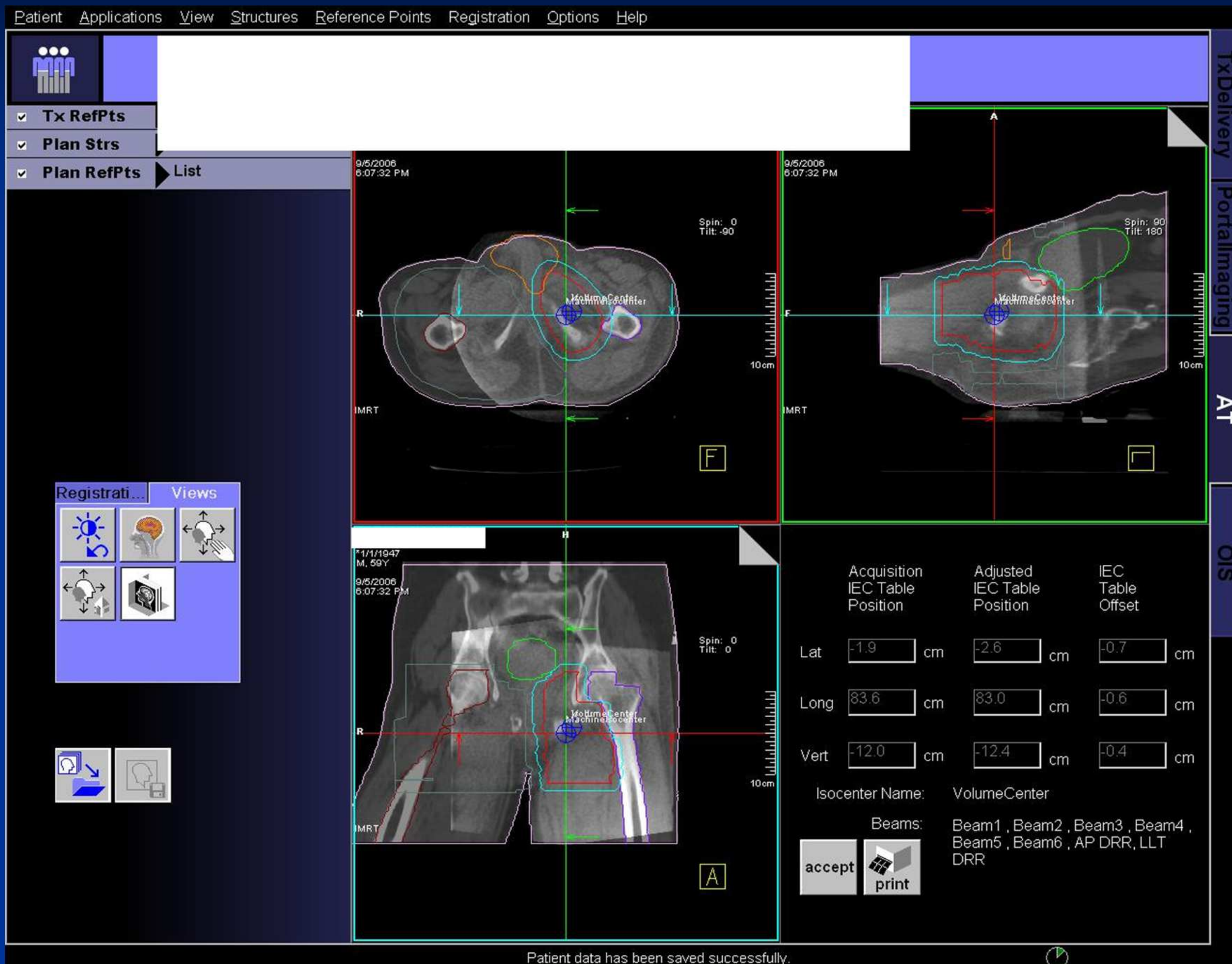


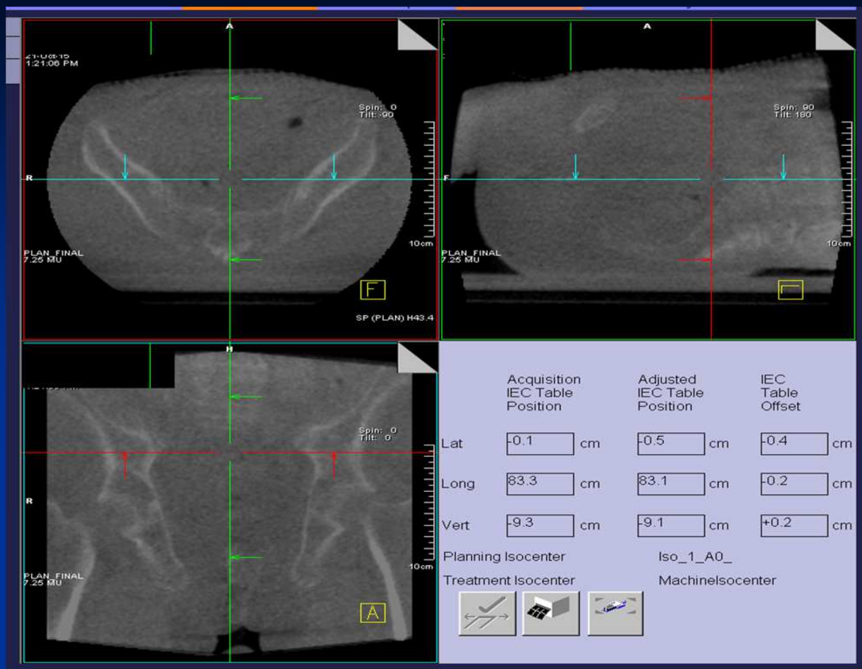


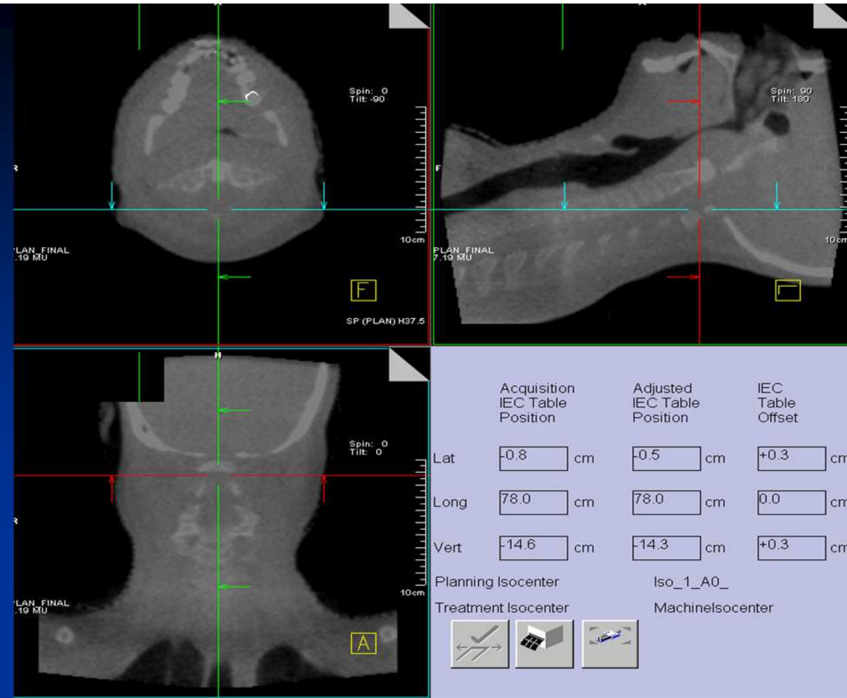




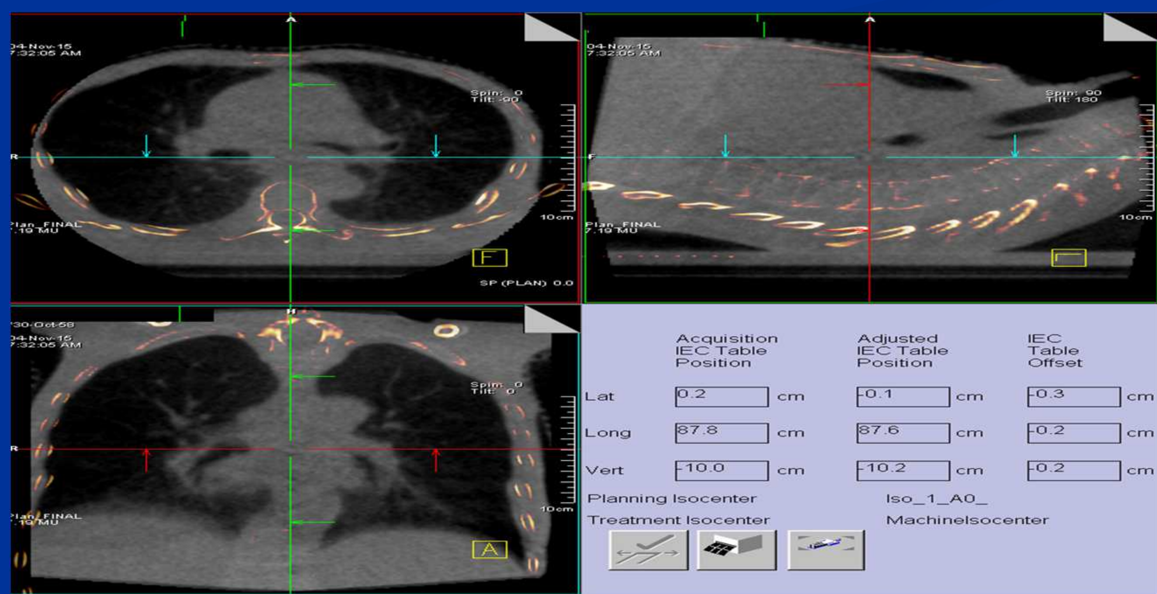
Hip Prosthesis with clear images and overlaying.







Full volume Artiste-MVCBCT images.

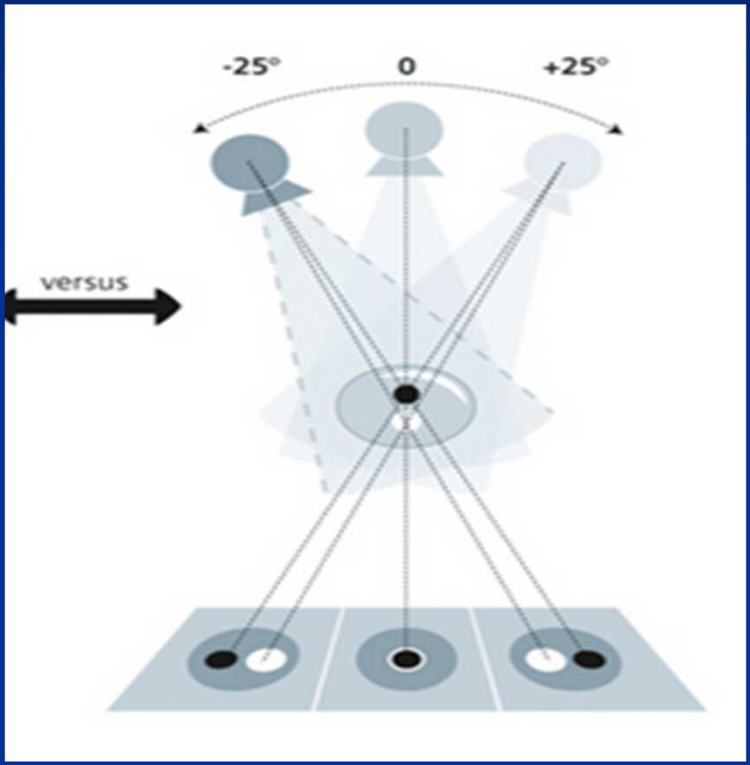


What are the –ve side of cone beam CT

- 1) Exposure to the patient is high
- 2) Rotation angle and time of acquisition is high.
- 3) Unwanted normal tissue gets exposed.

- In Tomosynthesis(DTS)
- --------- The exposure is relatively low
- -----------The rotation angle is 40°- 60°(65 deg).
- ------------It is limited to a particular region/site.

Digital Tomosynthesis(DTS)



Evaluation of three types of reference image data for external beam radiotherapy target localization using digital tomosynthesis (DTS)

Devon J. Godfrey,[a] Lei Ren, Hui Yan, Q. Wu, Sua Yoo, M. Oldham, and Fang Fang Yin
Department of Radiation Oncology, Physics, Duke University, DUMC 3295, Durham, North Carolina 27710

(Received 19 October 2006; revised 11 June 2007; accepted for publication 15 June 2007; published 30 July 2007)

Digital tomosynthesis (DTS) is a fast, low-dose three-dimensional (3D) imaging approach which yields slice images with excellent in-plane resolution, though low plane-to-plane resolution. A stack of DTS slices can be reconstructed from a single limited-angle scan, with typical scan angles ranging from 10° to 40° and acquisition times of less than 10 s. The resulting DTS slices show soft tissue contrast approaching that of full cone-beam CT. External beam radiotherapy target localization using DTS requires the registration of on-board DTS images with corresponding reference image data. This study evaluates three types of reference volume: original reference CT, exact reference DTS (RDTS), and a more computationally efficient approximate reference DTS ($RDTS_{approx}$), as well as three different DTS scan angles (22°, 44°, and 65°) for the DTS target localization task. Three-dimensional mutual information (MI) shared between reference and on-

Med.Phys. 34(8), Aug 2007, pp3374-3384

Digital Tomosynthesis(DTS)

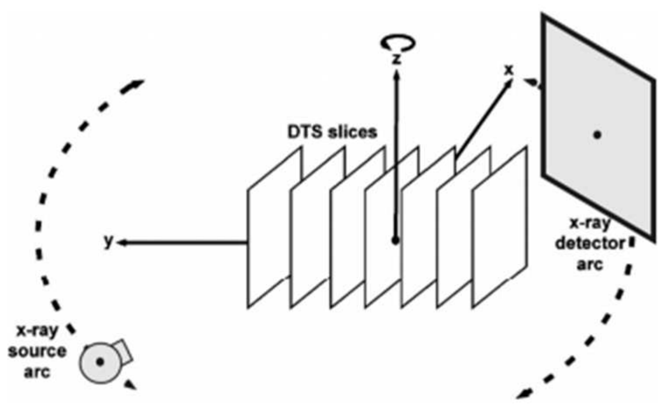


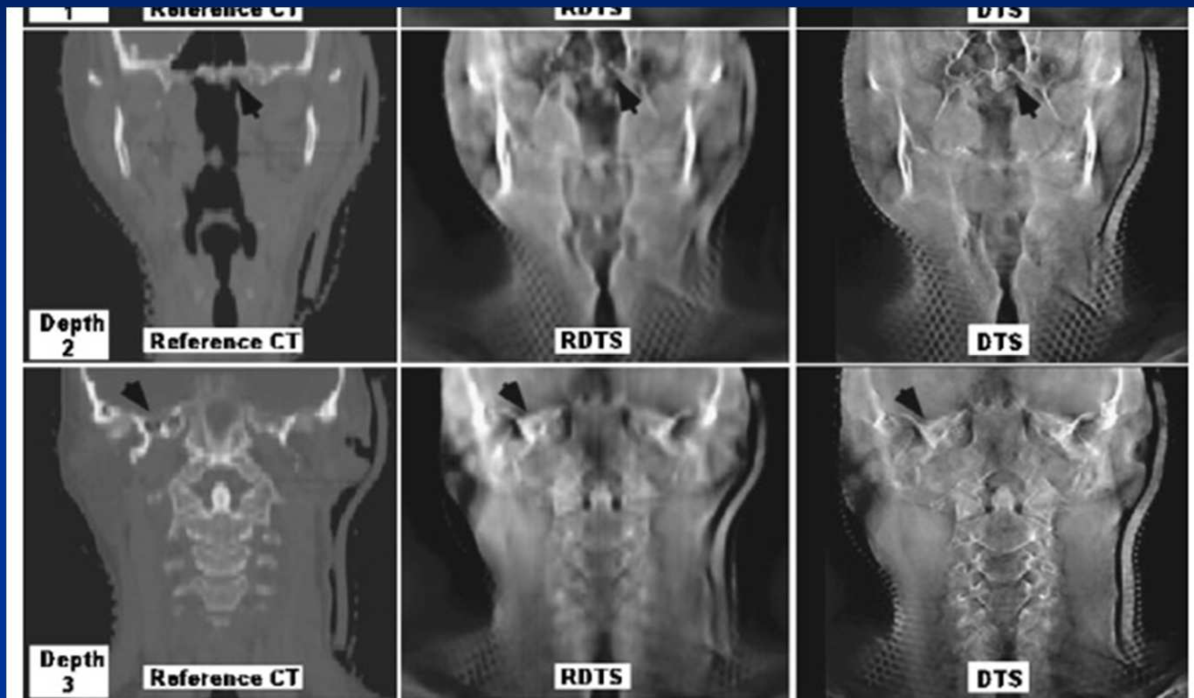
FIG. 1. Orientation of DTS slices.

Roatation time is maximum 12 sec
70 to 80 projections are used.
Reference DTS images are made from CT or CBCT data set.

DTS is an effective adjunct to the currently available IGRT methods.

It is possible to automate the DTS registration and localisation.
The reference DTS image is to be of 0.5mm thick. It means, the accuracy of acquisition and reconstruction is very demanding.
Three areas such as Soft tissue localisation(contrast is low), and deformable organ areas and organs that move make this very tricky to localise.

Digital Tomosynthesis(DTS)



Devon.J.Godfrey et al Med.Phys. 34(8), Aug 2007, pp3374-3384.
Duke Univeristy, North Carolina.

MV fan beam Imaging

- Imaging beam is detuned to lower value of 3.5MV
- Xenon gas elements are used for imaging.
- Image matrix is 512 x 512 with FOV 40 cm.
- Standard Jaw setting is 4mm for imaging mode.
- Nominal slice spacing is 2mm, 4mm and 6 mm.
- Rotational period for image acquisition is 10s.
- Imaging dose 1 to 3 cGy.
- Image
- -----quality is not very good in relation to kVCBCT

- Dose calculation is straight forward.
- It is easy for Adaptive Radiotherapy
- Sooner or later, the using departments do imaging only for a short length for aligning.

1.6mm resolution for the high contrast object.

2.5 MV beam.

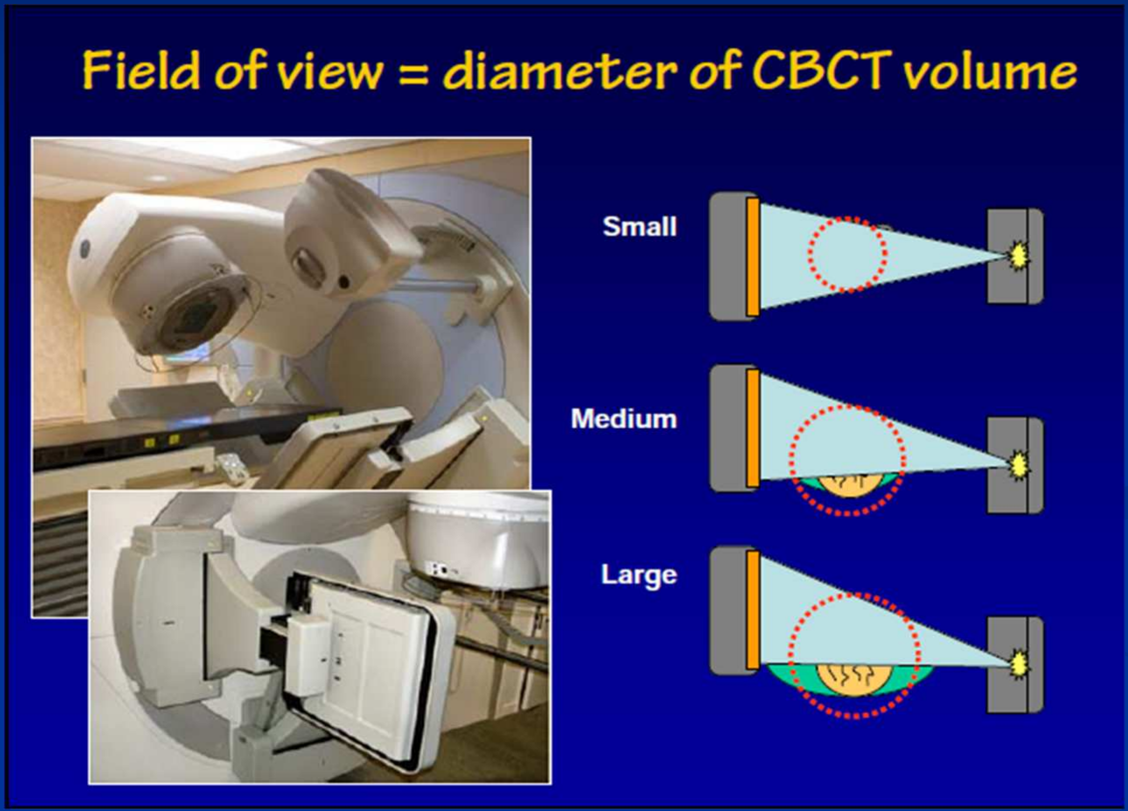
SU-E-I-72: First Experimental Study of On-Board CBCT Imaging Using 2.5MV Beam On a Radiother

Purpose: Varian TrueBeam version 2.0 comes with a new inline 2.5MV beam modality for image guided patient setup. In this work we develop an iterative volumetric image reconstruction technique specific to the beam and investigate the possibility of obtaining metal artifact free CBCT images using the new imaging modality. Methods: An iterative reconstruction algorithm with a sparse representation constraint based on dictionary learning is developed, in which both sparse projection and low dose rate (10 MU/min) are considered. Two CBCT experiments were conducted using the newly available 2.5MV beam on a Varian TrueBeam linac. First, a Rando anthropomorphic head phantom with and without a copper bar inserted in the center was scanned using both 2.5MV and kV (100kVp) beams. In a second experiment, an MRI phantom with many coils was scanned using 2.5MV, 6MV, and kV (100kVp) beams. Imaging dose and the resultant image quality is studied. Results: Qualitative assessment suggests that there were no visually detectable metal artifacts in MV CBCT images, compared with significant metal artifacts in kV CBCT images, especially in the MRI phantom. For a region near the metal object in the head phantom, the 2.5MV CBCT gave a more accurate quantification of the electron density more »

Authors: Xu, Q [1] ; Institute of Image Processing and Pattern Recognition, Xi'an Jiaotong University, Xi'an [2] ; Li, R ; Yang, Y ; Xing, L [1]

1. Department of Radiation Oncology, Stanford University, Stanford, CA (United States)
2. (China)

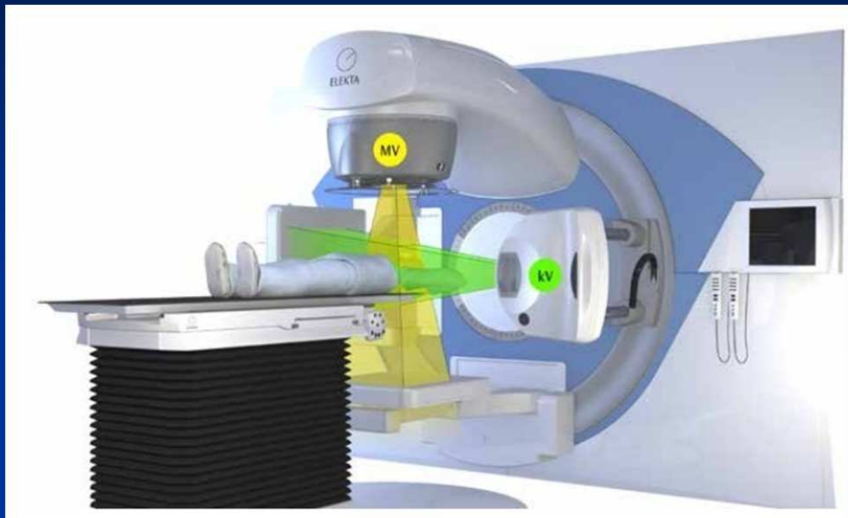
Publication Date: 2014-06-01



Coutesy:

Jorg Lehmann

Getting full FOV: White paper



re 1. Elekta Synergy® IGRT equipment in the treatment room.

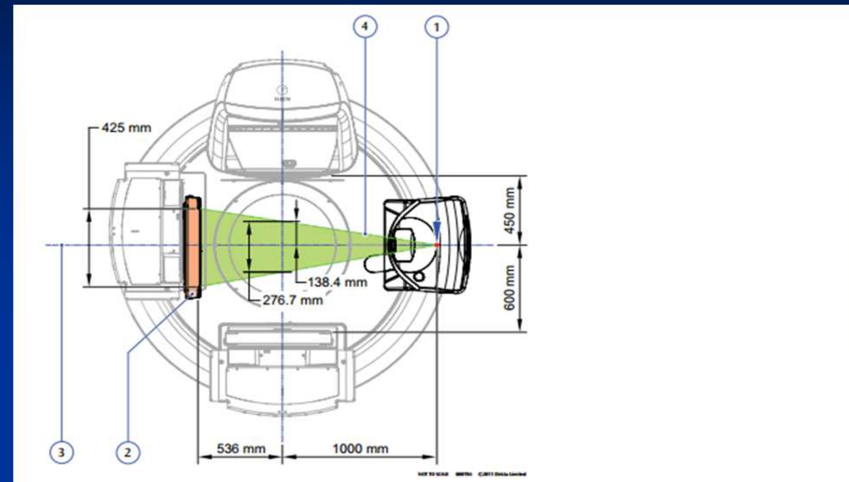
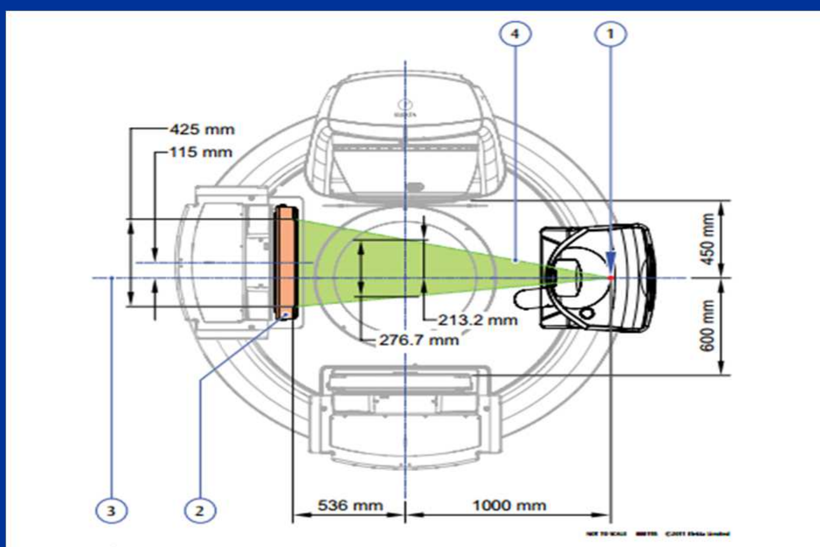
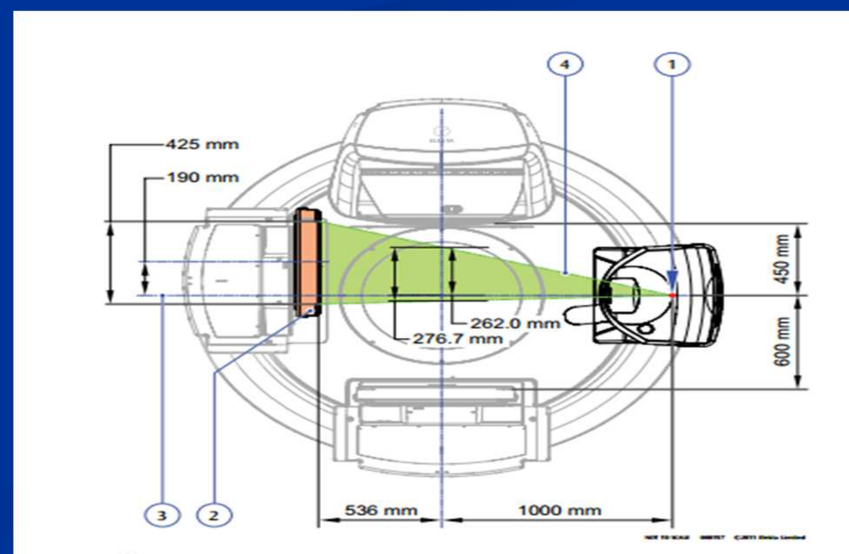


Figure 4. Image acquisition in small field-of-view position.
(1) kV X-ray beam reference axis (perpendicular to image receptor plane). (2) Focus point of the kV X-ray beam. (3) Projected X-ray field.
(4) Image receptor (kV detector panel).





Volumetric Imaging- Developments

- Shifts were used for correcting patient's position.
- Shifts were used to calculate systemic and random errors. Use them to arrive at PTV margins.
- 6D couch helped in implementing rotational errors.
- Volumetric Imaging helped think about Adaptive Planning.
- Real time imaging and its utilities.

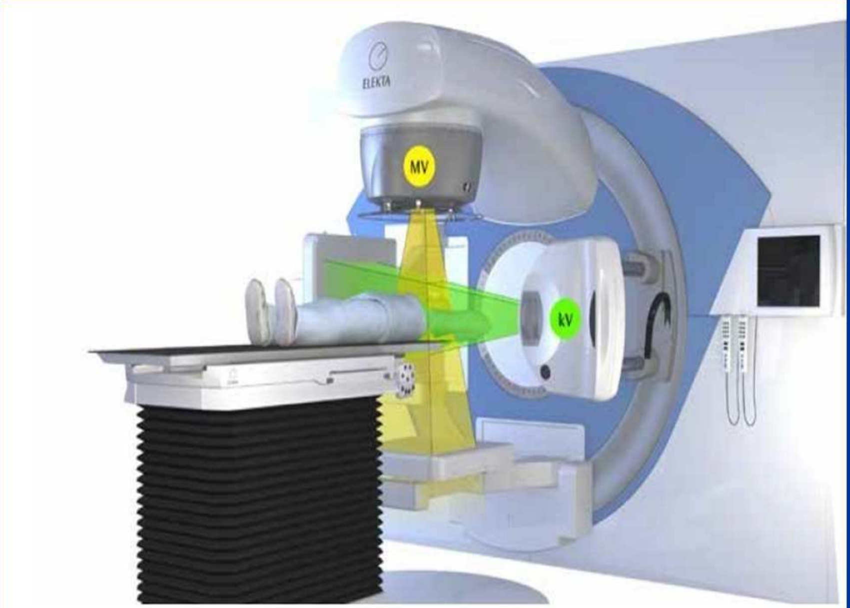


Figure 1. Elekta Synergy® IGRT equipment in the treatment room.

International Journal of
Radiation Oncology
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Physics Contribution

Verification of Planning Target Volume Settings in Volumetric Modulated Arc Therapy for Stereotactic Body Radiation Therapy by Using In-Treatment 4-Dimensional Cone Beam Computed Tomography

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- 15 Lung tumour cases.
- 5mm uniform margin to ITV
- Obtained kVCBCT for positioning.
- Planned for 50Gy/4f using VMAT
- Obtained 55 4DCBCT.

- The no of projections obtained during the 4DCBCT is double or more than the regular projections.

- The data sets belonging to the different phases of the breathing cycle were superimposed on planning images and movement limits are evaluated.
- Dose due to 4DCBCT is 30mSv(3DCBCT-15mSv)

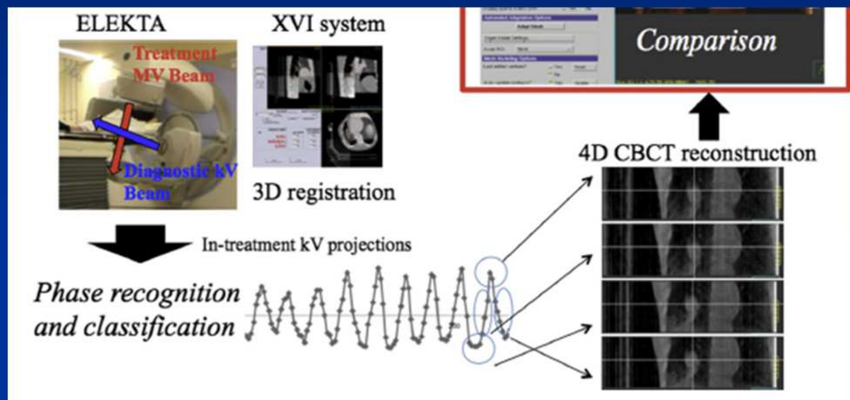


Fig. 2. Workflow of the verification of the PTV setting using in-treatment 4D CBCT.

Conclusion: The movement of the tumour edges lies within the limits of 5mm ITV.

KV CONE BEAM

- 0.75 lp/mm to 0.8 lp/mm
- ~ 0.66mm to 0.6 mm

MV CONE BEAM

- MVCBCT -> 0.4 lp/mm
  -> 1.25 mm
- CARBON TARGET -> 0.6 lp/mm
  -> 0.8 mm
- 2.5 MV Beam -> 0.75 lp/mm
  ~ 0.66 mm

So today, Real time imaging and its utilities is the real superiority of KV Cone Beam

- In line imaging or the imaging at perpendicular geometry, which one would last long or superior?

- If real time imaging does not move to the next step, then Inline Imaging would still be a countable choice!

SRS

- 1951----Lars Leksell coined the term "Stereotactic Radiosurgery"
- "the non-invasive destruction of intracranial . . . lesions that may be inaccessible or unsuitable for open surgery."
- -----Tried ortho voltage X-ray, particle beams and Linacs
- -------At last designed "Gamma Knife"

History GTC &BRW

TABLE 1-1. Historical landmarks in the development of SRS.

Year	*Author*	*Device/Event*
1951	Leksell	Invention of SRS with rotating orthovoltage unit
1954	Lawrence	Heavy-particle treatment of pituitary for cancer pain
1962	Kjellberg	Proton beam therapy of intracranial lesions
1967	Leksell	Invention of GK
1970	Steiner	GK SRS of AVMs
1980	Fabrikant	Helium ion treatment of AVMs
1982	Betti/Columbo	Linacs adapted for SRS
1984	Bunge	Installation of commercial GK
1986	Winston/Lutz	Linac SRS based on common stereotactic frame
1991	Friedman	Linac system for highly conformal SRS
1992	Loeffler/Alexander	Dedicated linac for SRS developed
1994	Adler	First CyberKnife treatment
1997	Krispel	Rotating cobalt unit

Steps

- Invasive frame or mask
- Imaging CT,MR and DSA if required.
- Fuse the images.
- Localize
- Target delineation
- Planning.
- Evaluation and approval
- Positioning on the table and verification.(6D couch)
- Treatment Delivery

Steps for frameless

- Mask preparation
- Imaging CT,MR and DSA if required.
- Fuse the images.
- Target delineation
- Planning.
- Evaluation and approval
- Positioning on the table and verify using volumetric imaging(6D-Couch).
- Treatment Delivery

Gamma Knifes

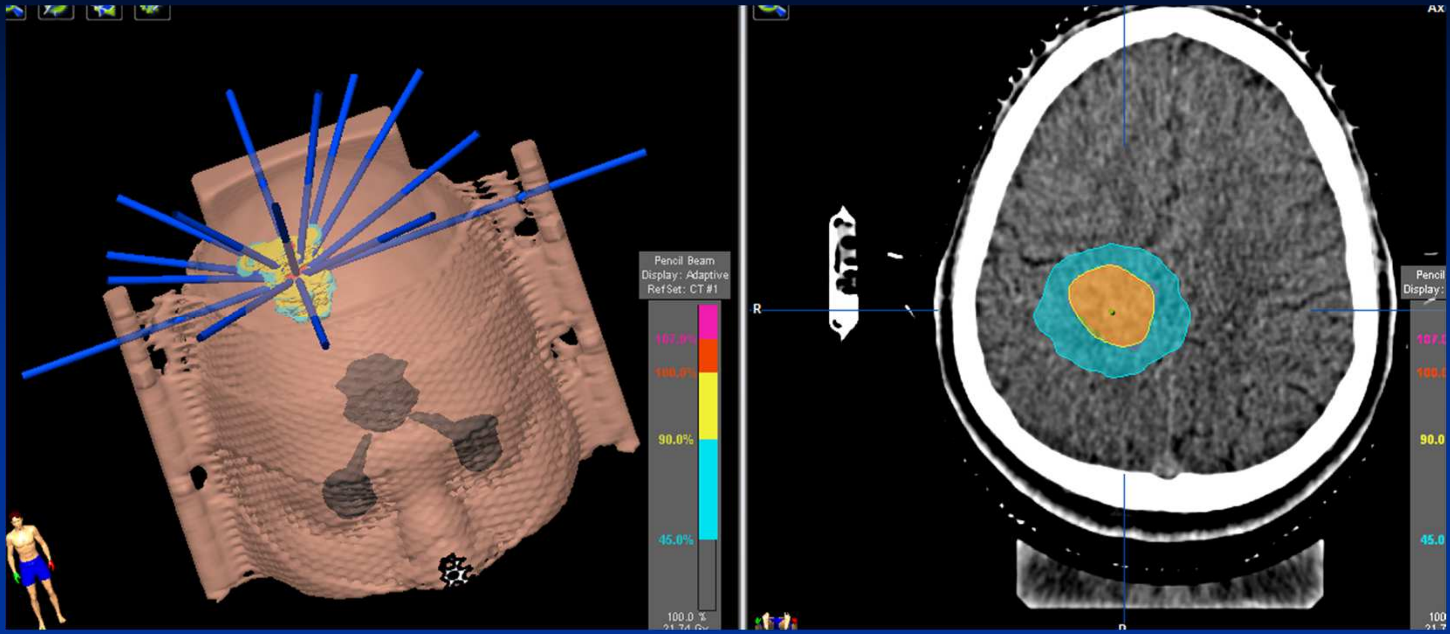
1) Gamma Knife-201 sources
2) Perflexion-192 sources-better collimator design.
3) Icon-2015: with image guidance- for microradiosurgery

Gamma Knife

- When the size of the lesion is below a cm and of the order of few mm, GK is the best device.
- Prescription in GK is 50%.
- Not really suitable to treat big lesions of the order of 20cc and above.

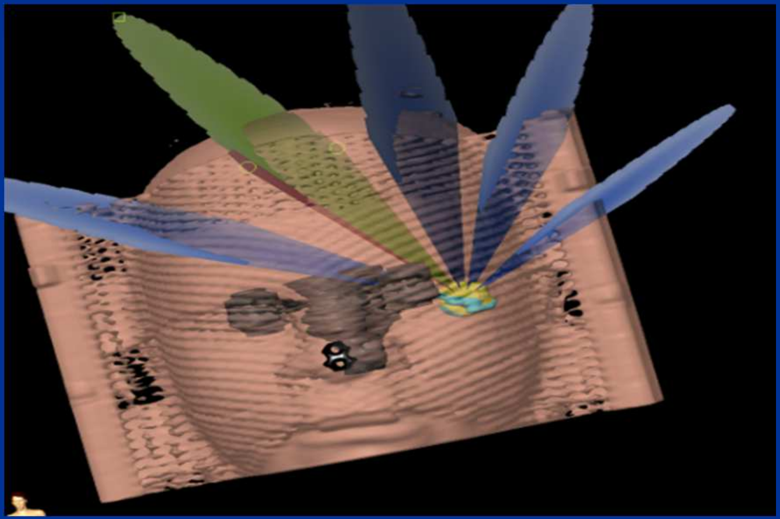
Accelerator based.

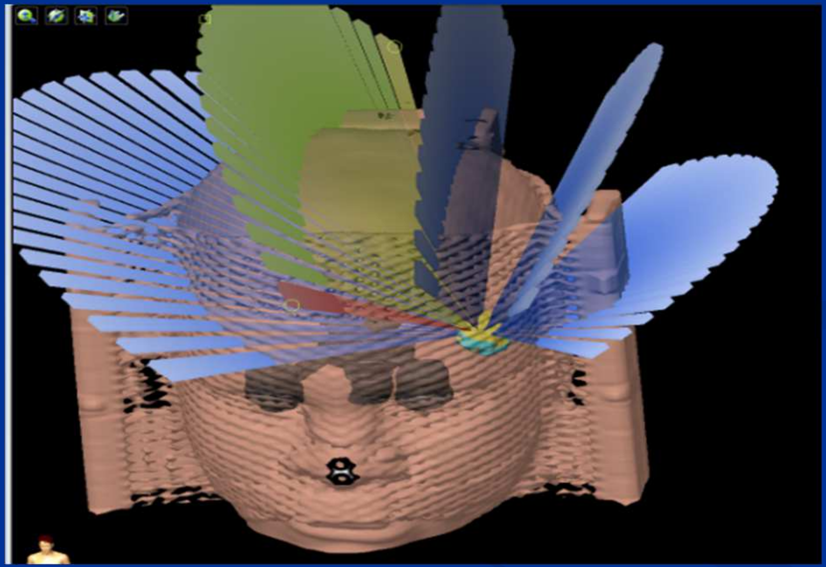
Circular collimator arc were the starting point. mMLC based multiple beams and arcs were started in later 1990s. Dynamic confonmal arcs were used in early 2000s. IMRS not really suitable of small lesions.



Conformal beams.
Direct as many as posiible
Make sure Mu/field is low
Ensure no overlap of beams.
Watch on skin dose.

Static conformal Arcs and Dynamic conformal Arcs.





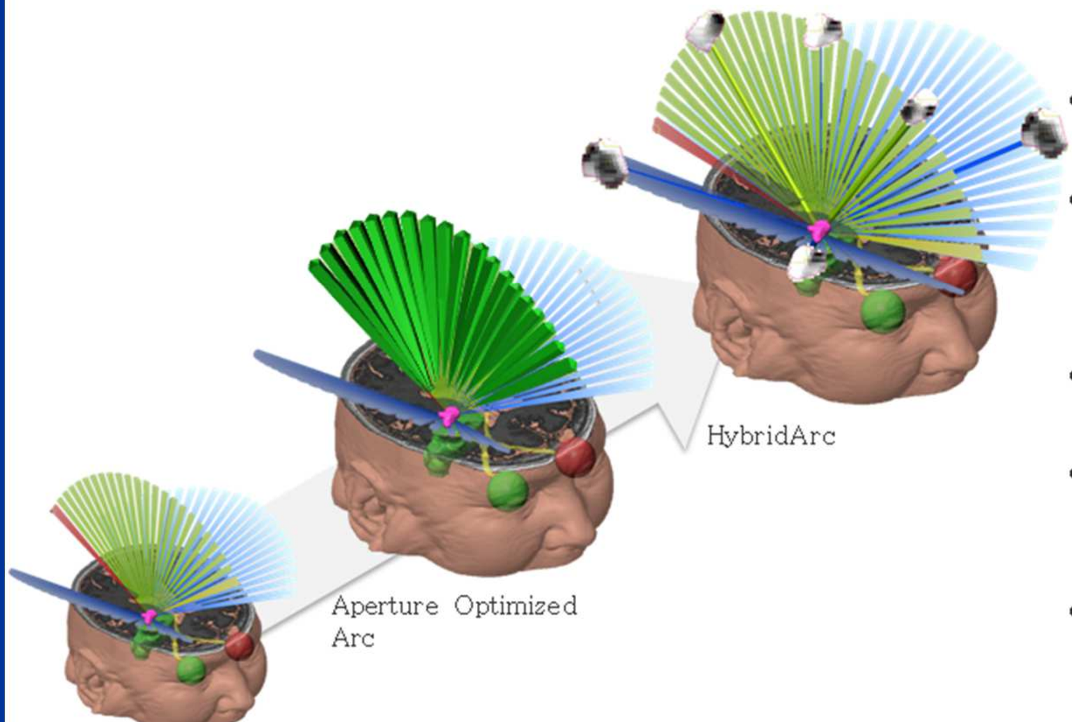
Fixed Gantry IMRS.

- For IMRS, beamlets are of size smaller than the MLC leaf widths. But, the lesion size is comparable to mMLC leaf width, so modulation was not very effective for small lesions of the order of cm and lower, so IMRS is not effective here.
- Hybric arcs and RapidArcs are really successful.
- Treating multiple lesions with single isocnter using RapidARC/VMAT is really effective methods.

Hybrid Arcs.

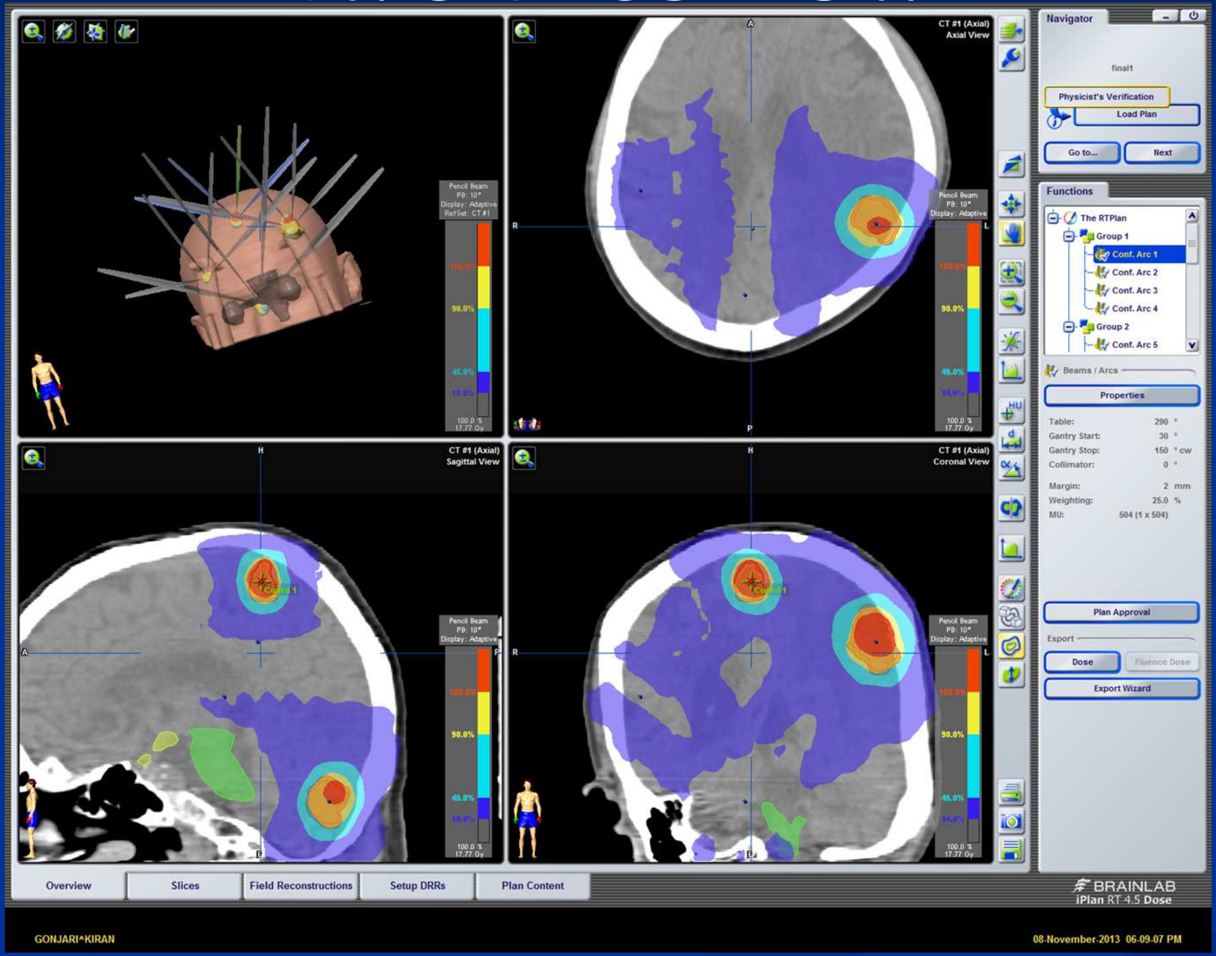
HYBRIDARC

EVOLUTION OF RADIOSURGERY



- Designed from the ground up for radiosurgery
- Automated and Optimized blending of Aperture Optimized Arc with Discrete IMRT
- Coplanar and non-coplanar planning with fast delivery
- Highly conformal templates for cranial and spine applications
- Software only upgrade enables nearly all Linac combinations

This can be treated with single or two arcs now



Robotic arm based system with complete degrees of freedom other than the angles that can block the integrated imaging system

During treatment, the imaging system repeatedly acquires and analyzes targeting radiographs, supplying updated target coordinates automatically through a control loop to the robotic arm.

- (1) The delivery of highly conformal dose distributions to irregular target volumes.
- (2) The delivery of fractionated stereotactic radiotherapy treatments,
- (3) The treatment of extracranial sites that are not amenable to localization and/or fixation using conventional stereotactic frames.

4) Nodes and pointing vectors give 1320 beams, out of which less than a few hundred are chosen and their weights are assigned.

5) The skull model, pelvis model and synchrony makes it accuracy to the fraction of a mm.

6) The accuracy for moving target also makes it sub mm accuracy.

SBRT

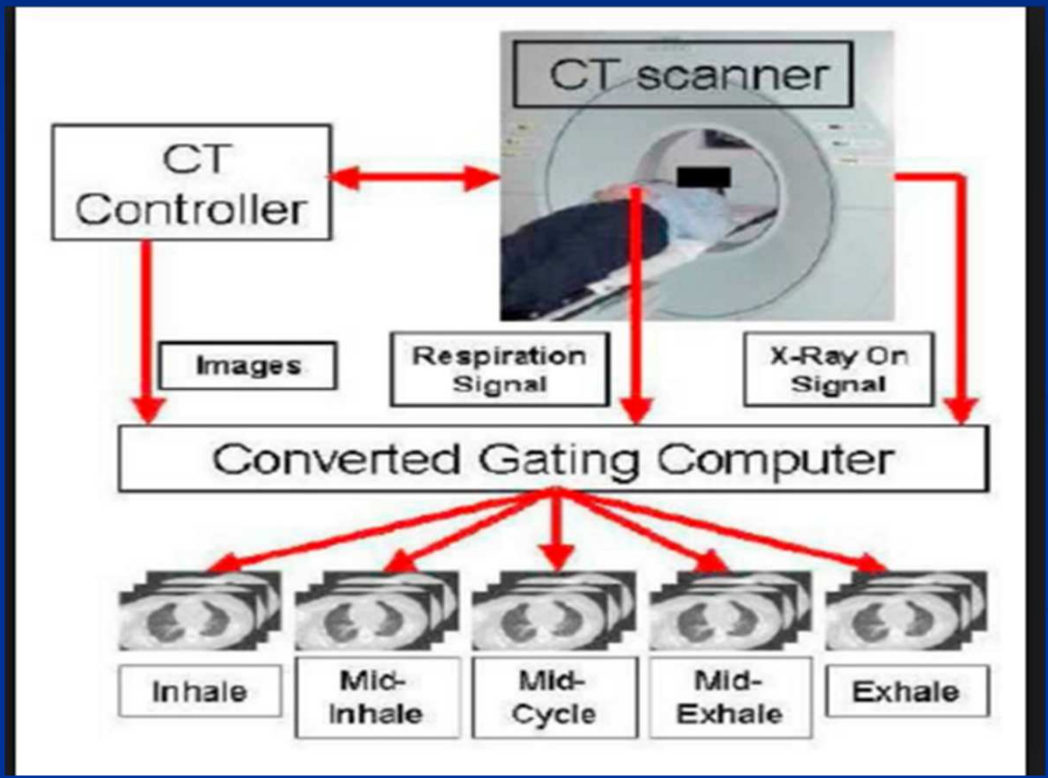
TABLE I. Comparison of typical characteristics of 3D/IMRT radiotherapy and SBRT.

Characteristic	3D/IMRT	SBRT
Dose/fraction	1.8–3 Gy	6–30 Gy
No. of fractions	10–30	1–5
Target definition	CTV/PTV (gross disease+clinical extension): Tumor may not have a sharp boundary.	GTV/CTV/ITV/PTV (well-defined tumors: GTV=CTV)
Margin	Centimeters	Millimeters
Physics/dosimetry monitoring	Indirect	Direct
Required setup accuracy	TG40, TG142	TG40, TG142
Primary imaging modalities used for treatment planning	CT	Multimodality: CT/MR/PET-CT
Redundancy in geometric verification	No	Yes
Maintenance of high spatial targeting accuracy for the entire treatment	Moderately enforced (moderate patient position control and monitoring)	Strictly enforced (sufficient immobilization and high frequency position monitoring through integrated image guidance)
Need for respiratory motion management	Moderate—Must be at least considered	Highest
Staff training	Highest	Highest+special SBRT training
Technology implementation	Highest	Highest
Radiobiological understanding	Moderately well understood	Poorly understood
Interaction with systemic therapies	Yes	Yes

Immobilization

- Top class immobilization which reduces the movement of the tumour below 5mm.
- Introduction of the ITV contour

4DCT imaging and binning



- Use ITV for moving tumour
- Use slice thickness of 1-2 mm
- Use as many beams as possible including non coplanar beams.
- Use gated delivery if required
- Use 5mm or 2.5 mm leaf width MLC
- Use volumetric imaging for IGRT.
- Prefer accurate dose calculation algorithms
- Use grid of 1 to 2mm.

- Use highly conformal disributions
- Use no of fractions not greater than 5.
- Use optical tracking if possible.
- Use appropriate inhomogenuity corrections.
- Ensure good implementation of small field dosimetry.
- Use techniques which have a low treatment times.

- Ensure a Medical Physicist is available in the starting of first treatment and Medical physicist is available within minutes for subsequent treatements.
- Ensure a Radonc is present during every fraction.
- Ensure a tight QA schedule is implemented in the entire chain of proccedure.


Thank You!