Image Guided Radiotherapy (IGRT)

Rationale: It is nowadays possible using IMRT to deliver a highly conformal radiation dose distribution –however treatment erros arising from patients geometry variation degrade the effectivenss of conformal RT for lesions in thorax and abdomen (esp. Ca. lung and prostate). IGRT techniques have been developed to handle these issues.
The **variations** between patient geometrty during planning and treatment arise from:

(1) patient positioning
(2) patient movement
(3) respirator, cardiac and peristaltic movement

Variation may be:

(1) Inter-fraction
(2) Intra-fraction

Errors in organ delineation in CT scanning can occur due to respiratory motion. These can be mitigated by:

(1) breath-holding during scan
(2) CT scan gating (scan only during one particular phase)
(3) 4D-CT scan (scan in all phases and sum up to cover the whole breathing cycle). This allows preparation of a radiation treatment plan that delivers dose at the desired point in the respiratory cycle.

Treatment of mobile tumors:
Traditionally, the approach has been to add margins to the CTV.
The goal of IGRT is to reduce the CTV-PTV margin, to reduce normal tissue complications and, at the same time, improve tumor control probability.
With proper patient set-up (eg use of implanted fiducial markers using daily setup photographs), the **inter-fraction** motion can be reduced to a negligible value.

Measures to reduce the variation in **intra-fraction** motion include:

(1) Use of proper internal margins-population-based or individual-based (using 4D-CT). The irregular margin thus produced is tighter than adding conventional uniform margins to the CTV.
(2) Control tumor motion using breat-holding/forced shallow breathing/abdominal compression
(3) Maintain a constant target position (called home position) when the beam is on, using respiratory gating, beam tracking or counch-based motion compensation.

(1) **Gating**:

Respiratory gatin limits the radiation exposure to portion of breathing cycles when the tumor is in the path of the beam. This is considered to be accurate, easily reproducible and tolerable approach.

(2) Beam tracking:

Target is followed dynamically with the radiation beam. It is done using dynamic MLC-considered ideal for extracranial sterotactic irradiation.

(3) Couch-based compensation:

Robotic couch moves in real time, in opposite direction of tumor motion, to cancel out the tumor motion in the BEV.

All techniques require the patient's compliance, and sometimes, active participation as well as extra participation from therapists.

Details of gating:

Tumor mass localization directly during treatment is difficult to impossible and hence surrogates, in the form of fiducial markers (internal/ external) are used commonly.

(1) **External gating system**: (eg RTRT of Mitsubishi)

Two passive infra-red reflective markers are used, placed on the patient's anterior abdominal wall which act as surrogates for respiratory motion. The patient's treatment geometry can thus be simulated and gating window set up.
Advantages:
(1) Non-invasive
(2) Easy
(3) No extra radiation dose required for imaging

Disadvantage: Errors can arise as tracking of external markers is not necessarily equivalent to tracking the tumor.

(2) **Internal gating system**: (eg RPM of Varian)

Uses 4 X-ray tubes placed at R & L cranial and caudal positions and image intensifier placed opposite.
X-ray units are synchronized with the Lineac. Fiducial markers implanted at the tumor site are directly tracked and Lineac is gated to irradiate the tumor only when the marker is within the internal gating window.
Advantage: Precise tracking of tumor possible.
Disadvantage:
(1) Invasive procedure
(2) Risk of pneumothorax and hemorrhage during placement of markers for lung tumors
(3) Chance of marker migration, leading to inaccuracy
(4) High imaging dose required for fluoroscopic tracking

(3) **Double gating**:

RPM gates on-board X-ray imaging system (IRIS) and imaging system gates the Lineac.

(4) Gating can also be done by **directly** correlating fluoroscopic images without implantation of radio-opaque fiducial markers

Treatment verification:

(1) Cine EPID-liquid ionization chamber-based /camera-based→uses exit image, hence not suitable for IMRT
(2) IRIS→KV/MV
(3) Electro-magnetic transponders

DART= replanning based on tumor motion. It can be:

(1) online (daily)
(2) real-time (during treatment)
(3) off-line (in between fractions)

SMART=DART + IMRT