Tecniche Treatment Planning System (TPS) per fasci di fotoni ed elettroni

Faiza Bourhaleb-Torino 27 Feb.

Radioterapia Conformazionale

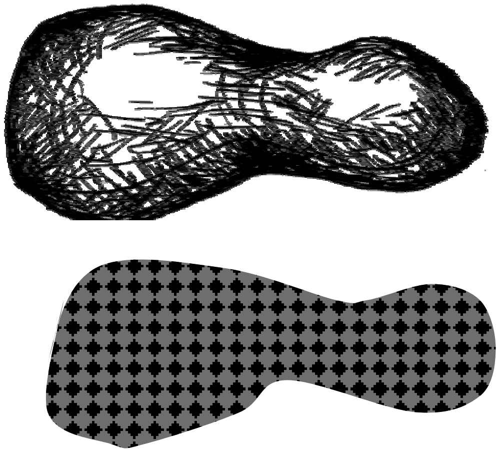
Introduzione alla Pianificazione di trattamento

Ottimizzazione in TP

Calcolo di dose finale

Fasci di elettroni - cenni

Radioterapia Conformazionale

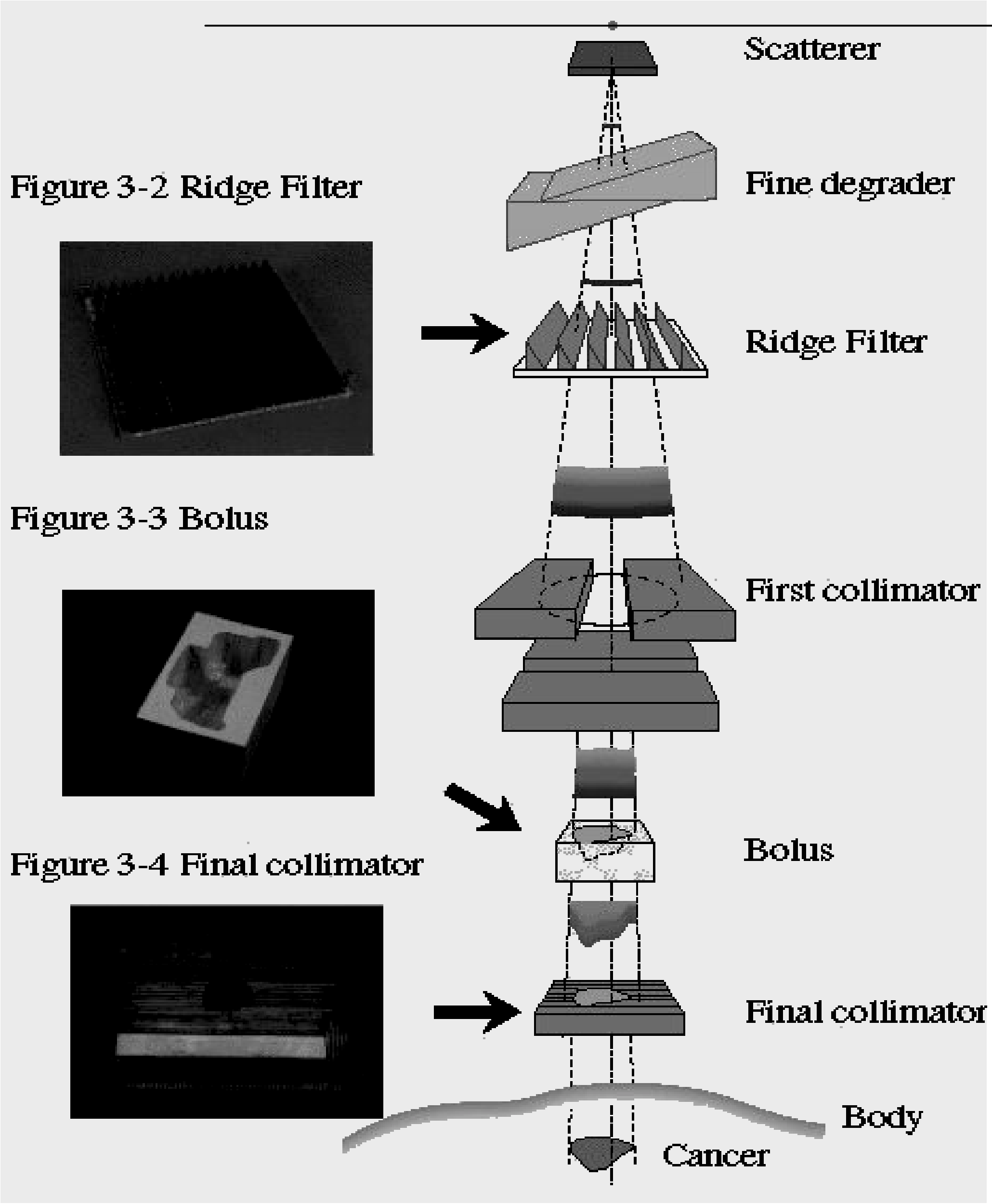


L’obbiettivo della radioterapia conformazionale, che è stata introdotta dalla radioterapia tri-dimensionale, è di realizzare una distribuzione di dose ben modellata alla forma del tumore in tutte le direzioni.

Il fascio non arriva più rettangolare, ma è delimitato con collimatori in modo che possa vedere la forma giusta del target.

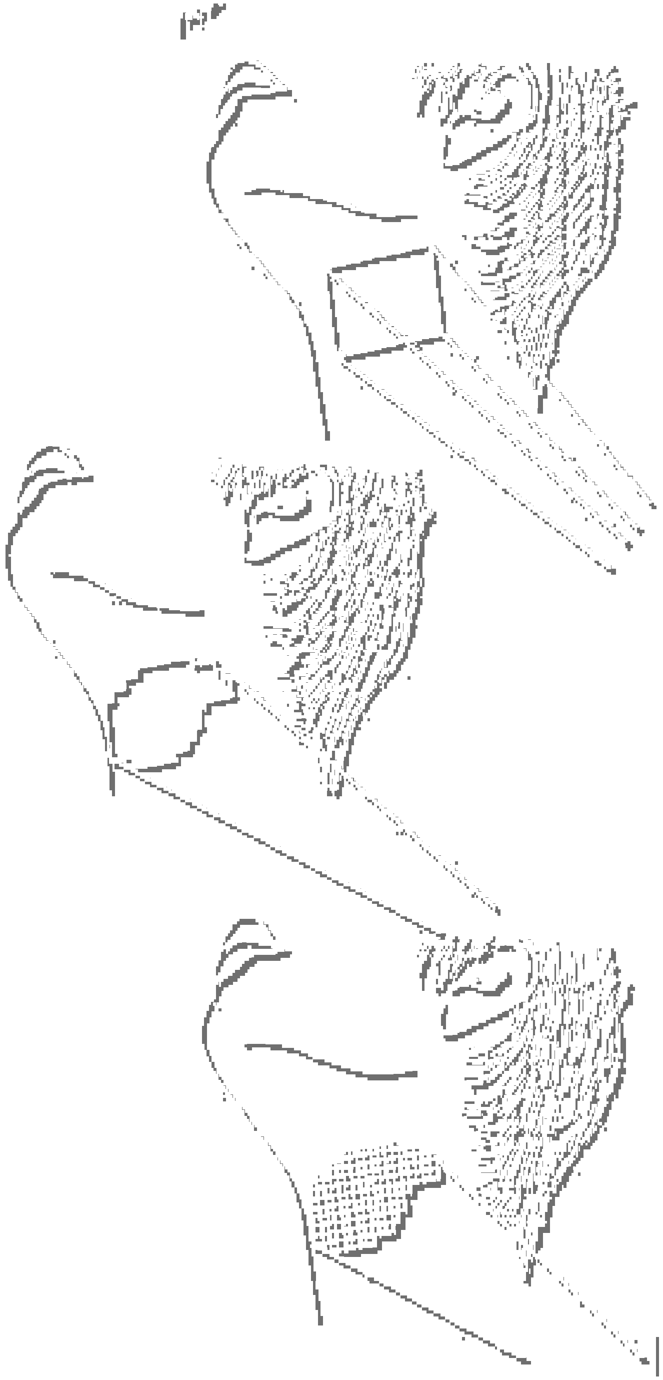
Per poter essere più conformi alla geometria e alla forma del tumore in profondità, servono degli ‘ostacoli’ adatti da mettere all’ uscita del fascio per attenuarlo in alcune posizioni. In questo modo la dose viene conformata in 3D.

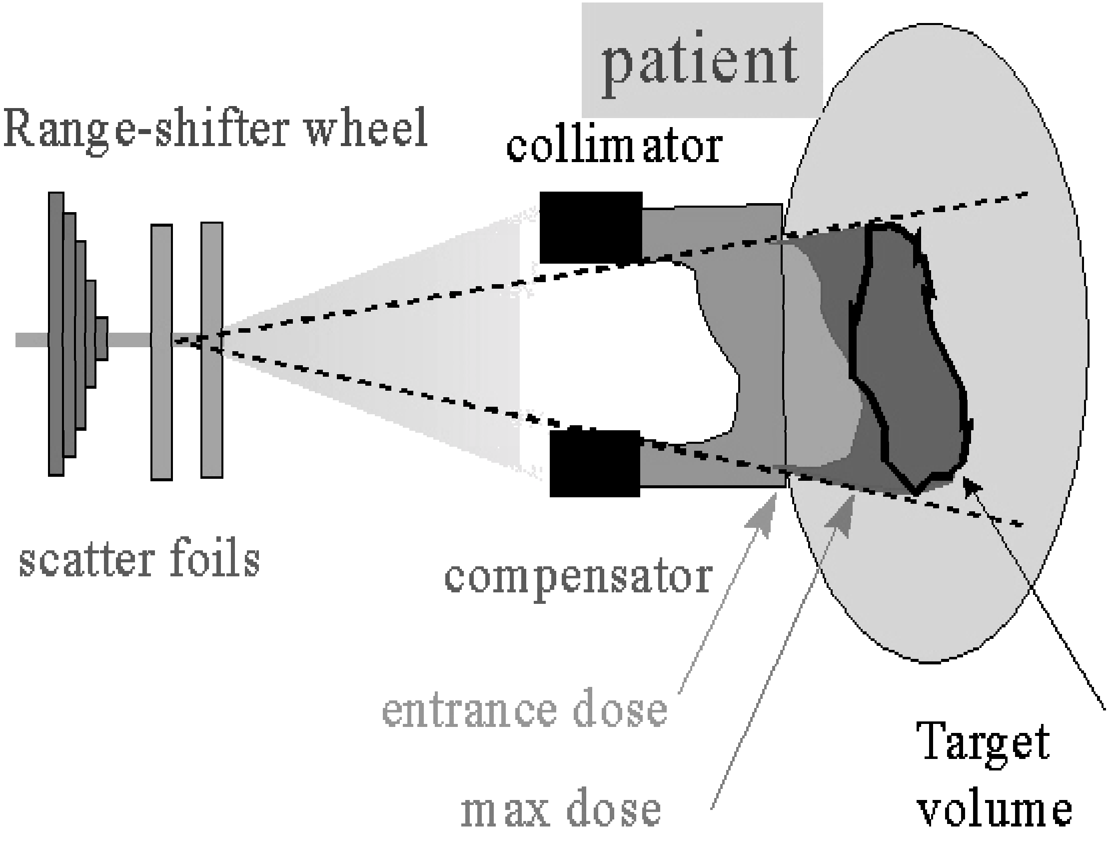
Radioterapia Conformazzionale



Accessori per la conformazione della dose al Target:

- Compensatori (spostamento del massimo in profondità)
- Ridge filter (allargare il massimo)
- Collimatori (delimitare il fascio lateralmente)
- Cunei (inclinare la distribuzione di dose con un angolo predefinito)
- Bolus (Tumore non profondo)
- Collimatori Multi-Lamellari (MLC) (=> Tecniche della radioterapia con intensità modulata, IMRT.)





patient

Range-shifter wheel

collimator

scatter foils

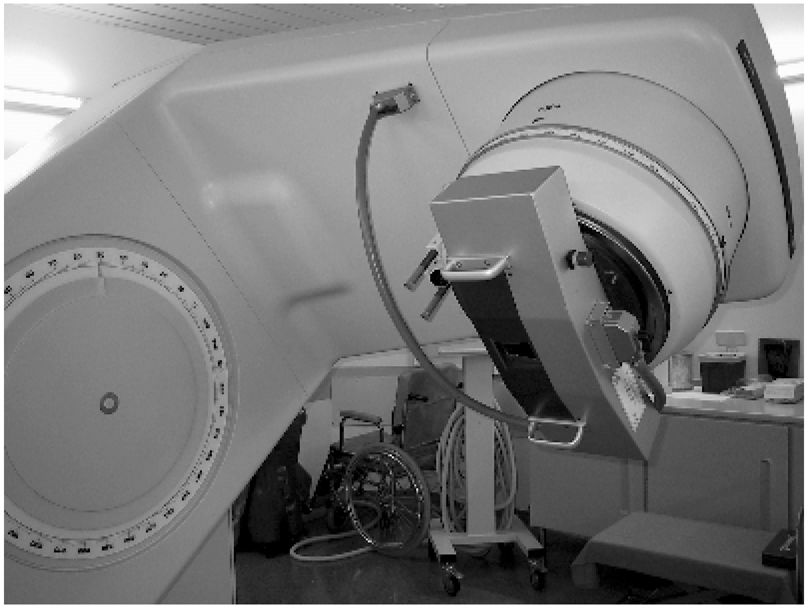
compensator

entrance dose

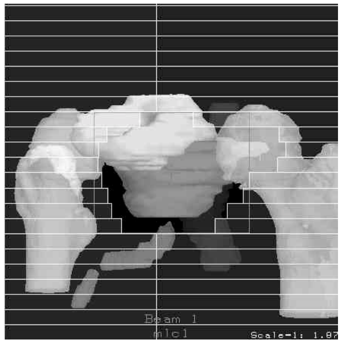
max dose

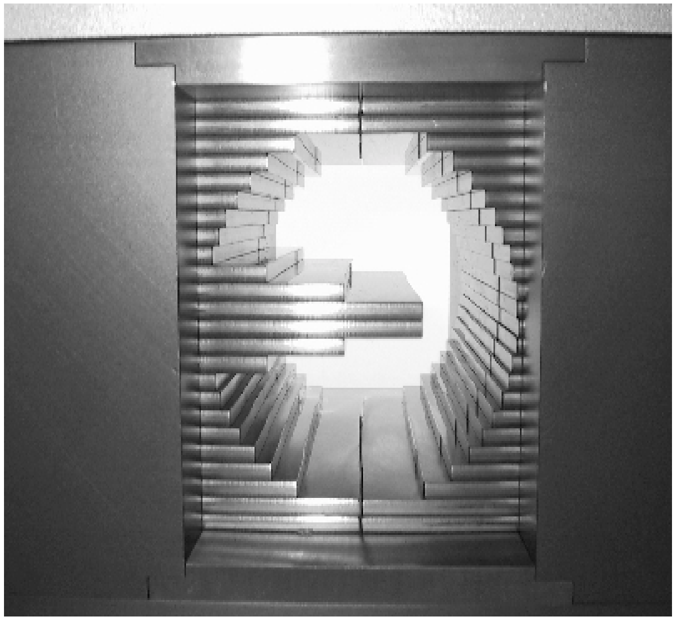
Target volume

L'inizio della IMRT => MLC.

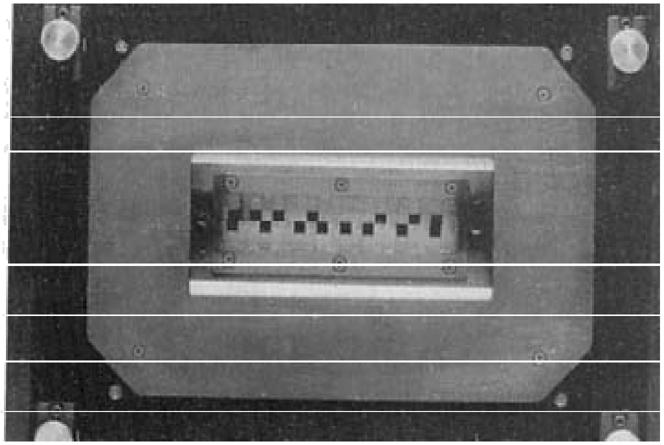


☚ Gantry con MLC dinamico

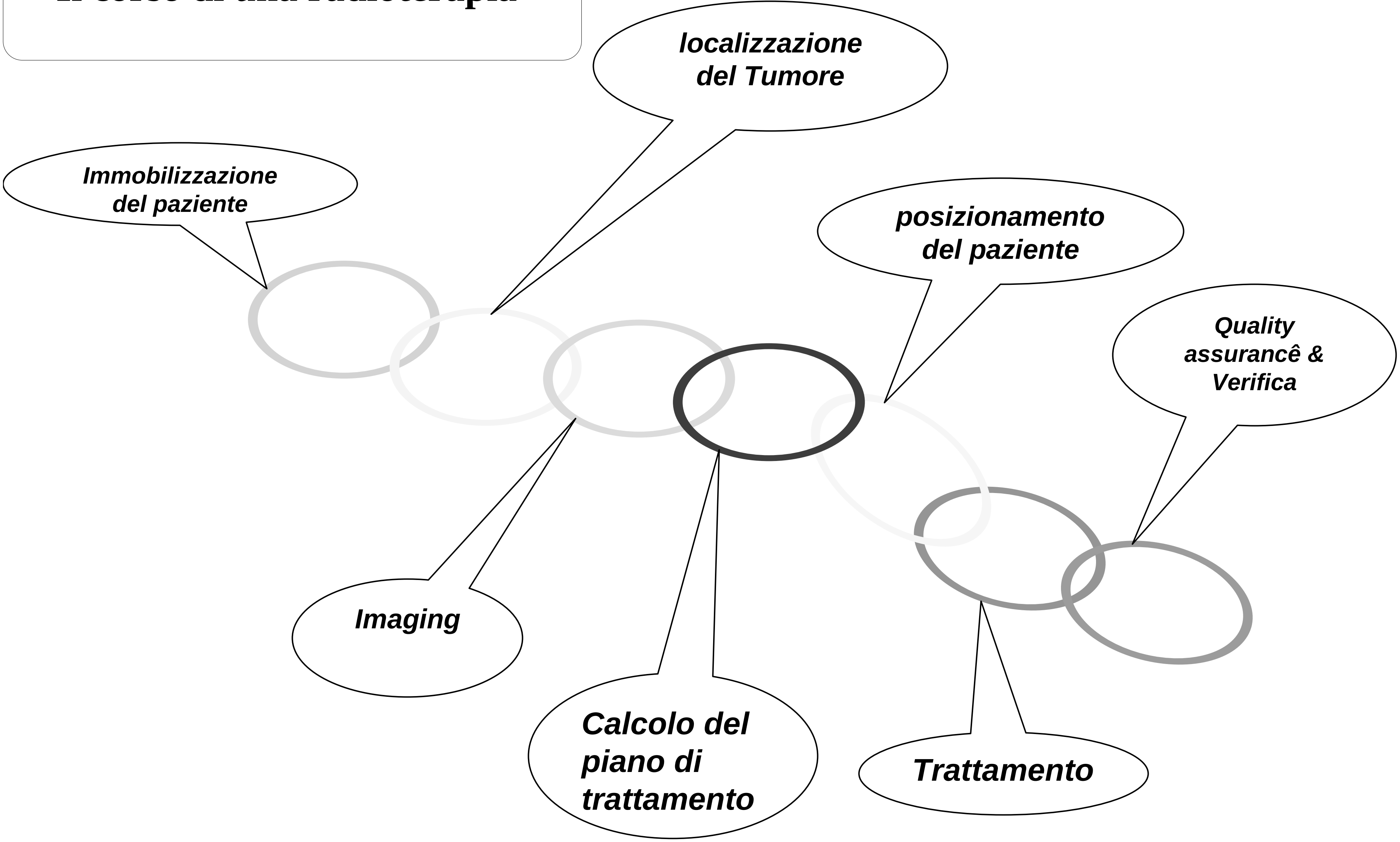




☚ The Multivane Intensity modulating Collimator (MIMIC).



Il corso di una radioterapia



Immobilizzazione del paziente

localizzazione del Tumore

Imaging

Calcolo del piano di trattamento

posizionamento del paziente

Trattamento

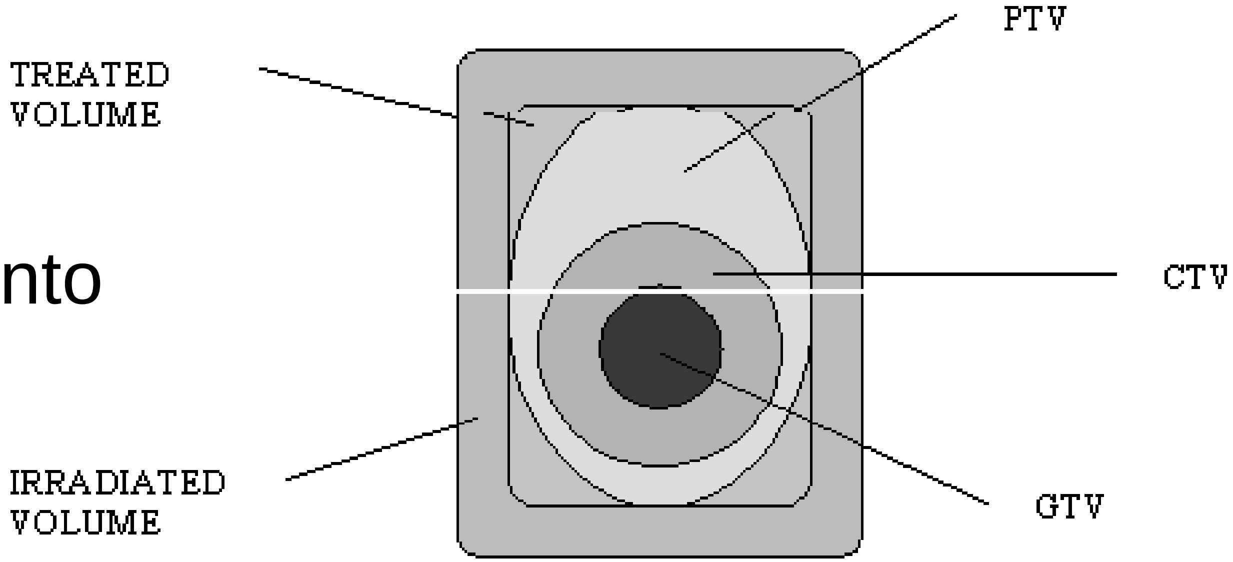
Quality assurancê & Verifica

Immobilizzazione

Il ‘design’ e la tecnica d’immobilizzazione sono legati alla localizzazione del tumore e al tipo di sorgenti di errori dovuti al tipo di zona trattata.

Definizione dei volumi Target =>

Volumi di riferimento



GTV gross tumor volume: volume e locazione visibile delle cellule maligne
CTV clinical target volume: tiene conto delle propaggini microscopiche
PTV planning “ “ : incorpora i margini associati a incertezze nella determinazione del CTV, posizionamento, movimenti del paziente durante l’irradiazione

Sorgenti di errore

Le possibili sorgenti di errore sono classificate principalmente in due categorie:

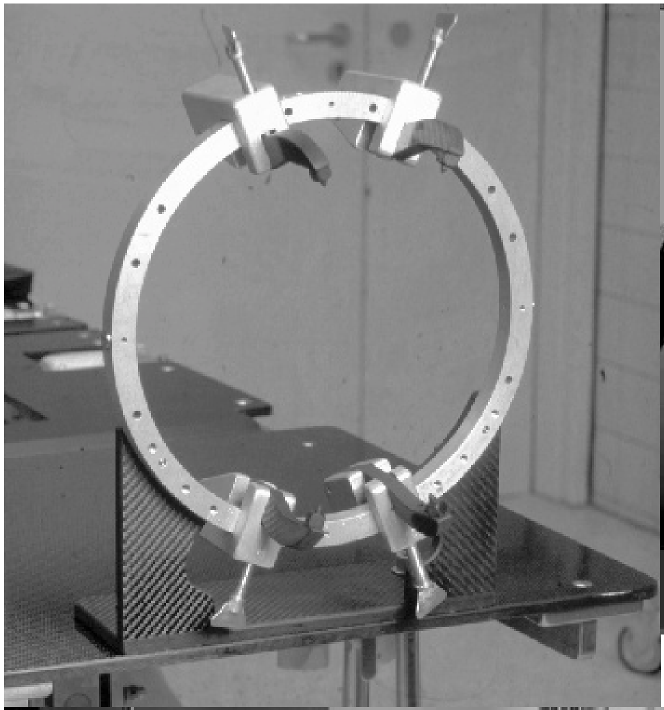
- Setup e posizionamento.

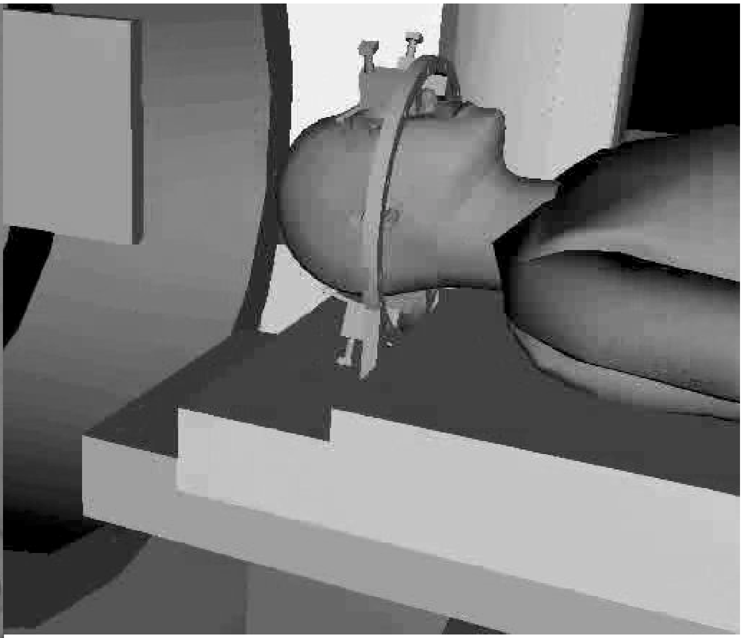
- Movimento degli organi.

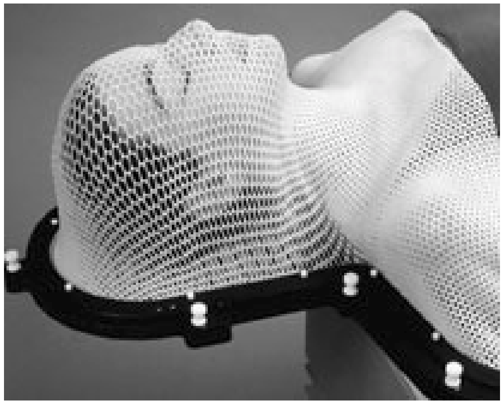
Le tecniche d’immobilizzazione devono assicurare che il CTV sia ben localizzato nel PTV durante l’intero trattamento (tutte le frazioni).

Una buona definizione dei margini di errore nel posizionamento e nei possibili movimenti (respiratori…) durante il trattamento è di grande importanza nel prevedere le correzioni del piano di trattamento e nel rispettare le norme della ‘quality assurance’.

Tecniche d’imobilizzazione

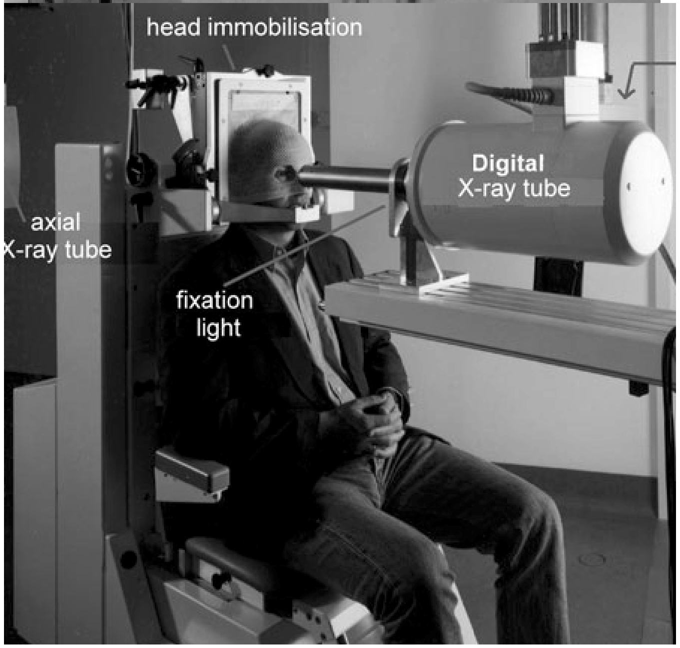






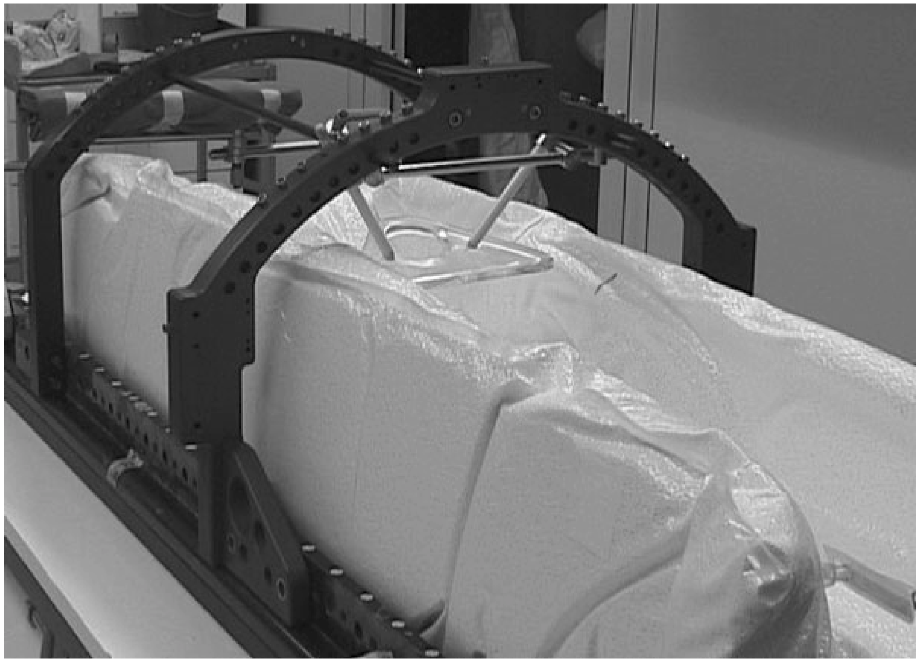
Stereotassi:

- Fissaggio con anello
- Fissaggio con maschera termoplastica



- Occhio: maschera

- altro: tecnica del vuoto.



Imaging for Therapy

Definizione dell’ utilità dell’ imaging per terapia:

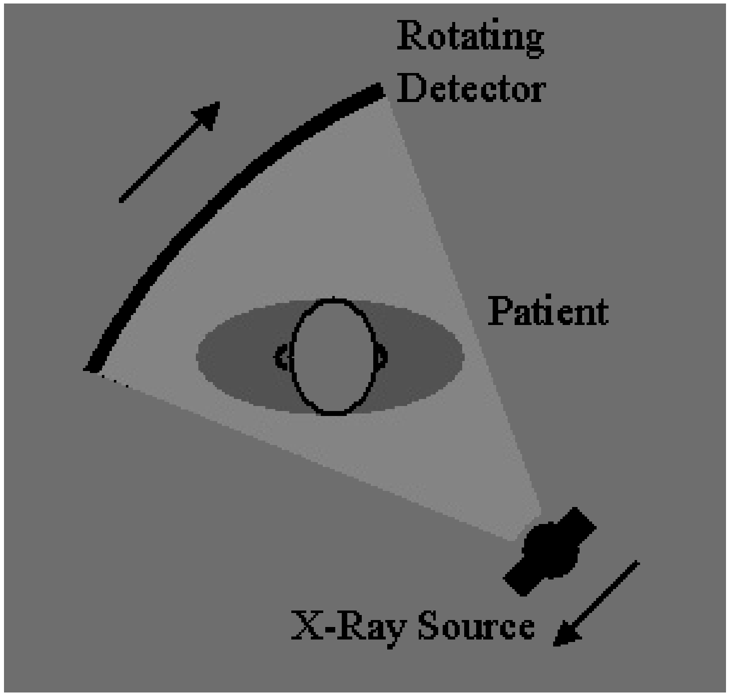
Quando il paziente è ben immobilizzato, l’immagine per la pianificazione del trattamento è neccessaria. Le immagini della diagnostica non sono considerate in questo corso. Le immagini per la pianificazione della terapia servono per i motivi seguenti:

- Distinguere il volume target e gli organi a rischio è il principale scopo dell’ acquisizione delle immagini per terapia. Basandosi sul modello tri-dimensionale ricostruito dell’ anatomia del paziente, la direzione del fascio viene ottimizzata per trovare un compromesso fra la copertura del tumore con una dose massima e il risparmio degli organi a rischio vicini.

- Nella magior parte dei casi la dose è calcolata basandosi sui dati della TAC dei volumi d’iteresse.
Calcolando la distribuzione di dose nelle diverse regioni si può valutare la qualità del piano di trattamento in 3D.

- Un modello tri-dimensionale dell’ anatomia del paziente è richiesto per il posizionamento del paziente. Spesso servono punti di riferimento sulla maschera del paziente per collegare il modello 3D della TAC con il resto (lettino,accessori, fascio...)

CT (TAC)

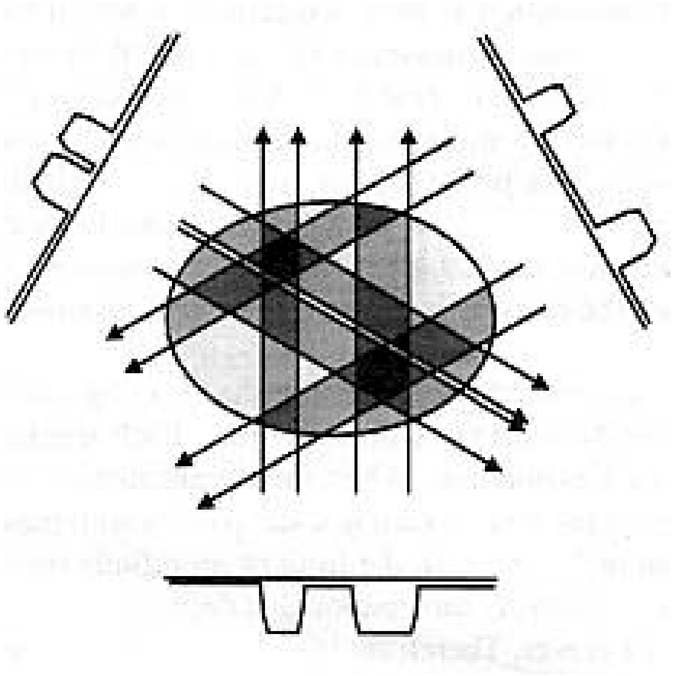


$I = I_0 \exp\left(-\int \mu(x,y)\, ds\right)$ $\int \mu(x,y) \cdot ds = -\ln(I / I_0)$ => µ

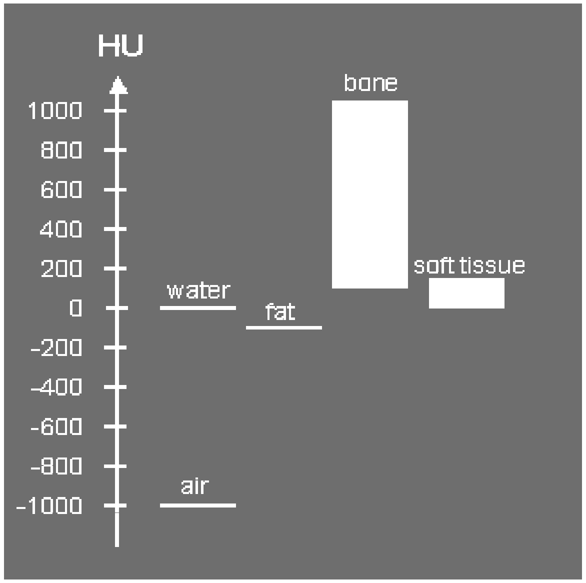
The value I is measured by the detector.
The incident intensity I_0 is obtained from a calibration scan without the patient.
Each line integral is therefore calculated from the measured data.

A complete set of line integrals, based on all projections of a 360° scan, iscalled a sinogram. From these CT raw data, a cross section is obtained by applying the mathematical method of filtered backprojection. The term backprojection refers to the distribution of all measured values along the corresponding projection ray.

A simple backprojection yields very blurred images, which show only the contours of high contrast structures. Sharp CT images are reconstructed when a particular filter is applied during backprojection.



$$H = \frac{\mu - \mu_W}{\mu_W} \cdot 1000$$

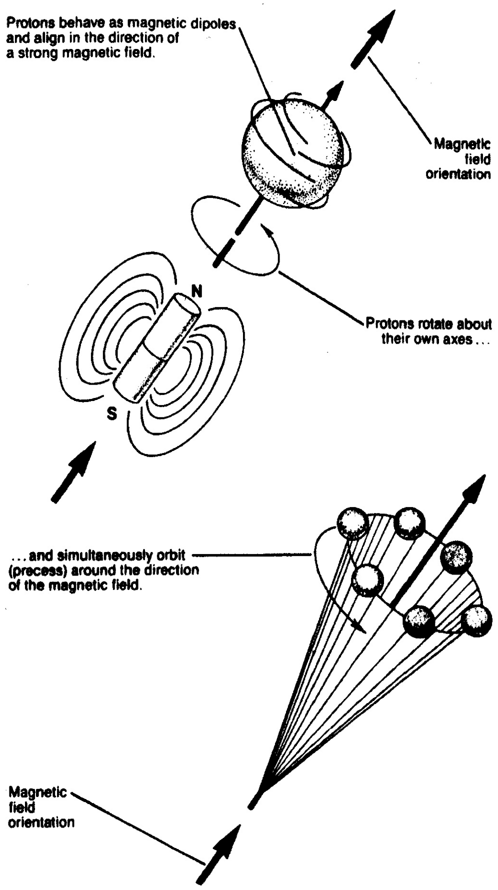


Magnetic Resonance Imaging MRI

Magnetic resonance imaging (MRI) is based on the principles of nuclear magnetic resonance (NMR).

The signal source in MRI can be any nucleus with nonzero spin or angular momentum. However, certain nuclei give larger signal than the others. Hydrogen nuclei (P), because of their concentration in tissues, produce signals of sufficient strengh for imaging. Currently, routineMRI is based exclusively on proton density and proton relaxation characteristics of different tissues.

Magnetic resonance imaging (MRI) provides outstanding possibilities for the definition of target volumes in radiation treatment planning. The high contrast for soft tissue regions makes MRI especially useful for use in tumors of the brain.
A basic problem with the use of MRI for stereotactic methods is the appearance of geometric distortions which are caused by eddy currents. These errors can be minimized by using wooden or ceramic stereotactic systems or Scotch casts for patient immobilization as alternatives.
The remaining errors can then be corrected with suitable phantom measurements and algorithms. Thus, sufficient correlation of MRI with CT, PET and ultrasound can be achieved.

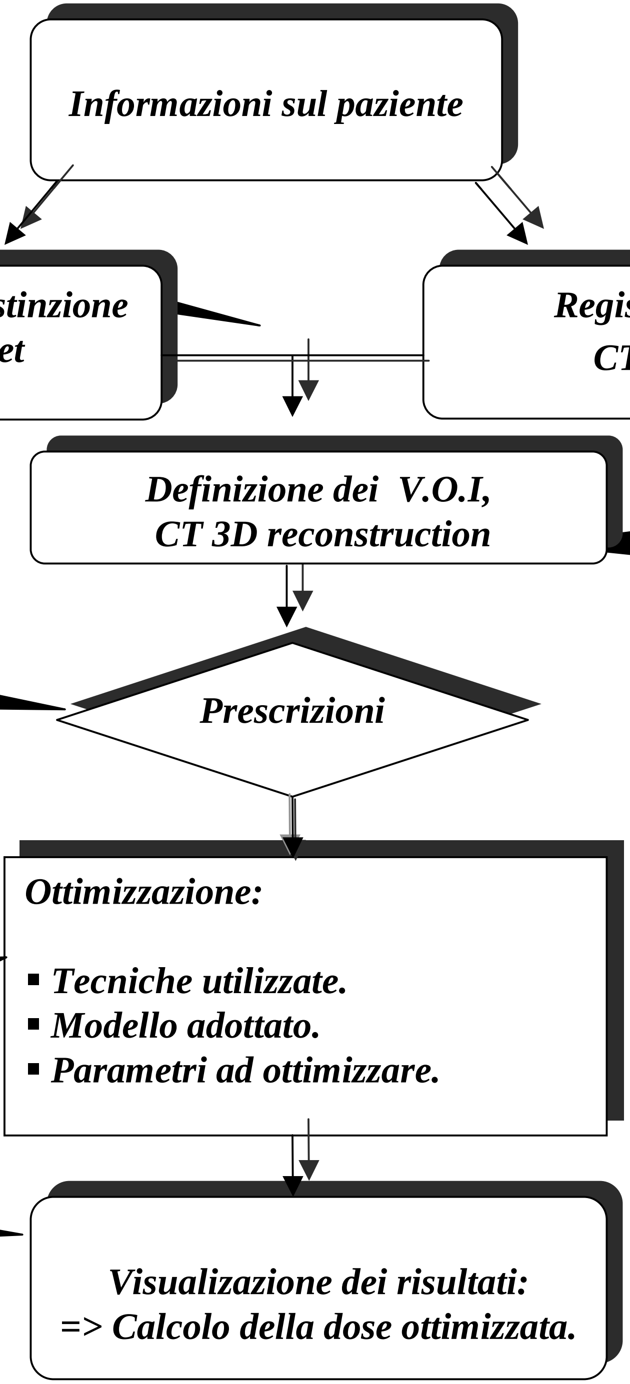


Alignement and precession of protons in a strong magnetic field.

Pianificazione di trattamento

The goal of 3D treatment planning is the evaluation and optimization of alternative treatment strategies before treatment, to find the optimal treatment plan for the patient.

With the 3D treatment planning the individual geometric relations between target volume and organs at risk should be considered correctly. Based on an individual three-dimensional model of the patient's anatomy, the beam portals can be shaped exactly to the form of the target volume. In this way, it is possible to minimize the dose to surrounding healthy tissue and radio-sensitive structures.



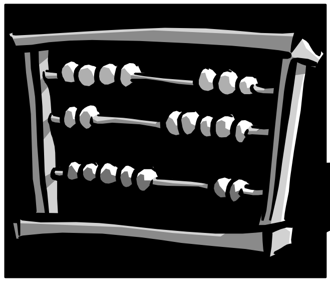
Informazioni sul paziente

Anatomia e distinzione del target

Registrazione CT/MRI

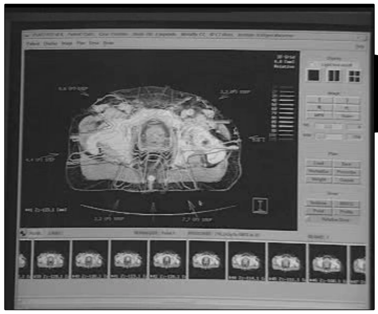
Definizione dei V.O.I, CT 3D reconstruction

Prescrizioni



Ottimizzazione:

- ***Tecniche utilizzate.***
- ***Modello adottato.***
- ***Parametri ad ottimizzare.***



Visualizzazione dei risultati:
=> Calcolo della dose ottimizzata.

<u>Diverse tappe della pianificazione di trattamento:</u>

- Informazioni sul paziente
- Tipo di tumore e prescrizioni
- Calcolo della dose finale

Ricostruzione in 3D

The process of distinguishing relevant structures/volumes from the background is called segmentation. Segmentation methods that are based on the image information of one slice are called 2D-segmentation. If the information of more than one slice is used, the process is called 3D-segmentation. In radiation treatment planning, segmentation is done by delineating the PTV, the organs at risk and the surface contour of the body.

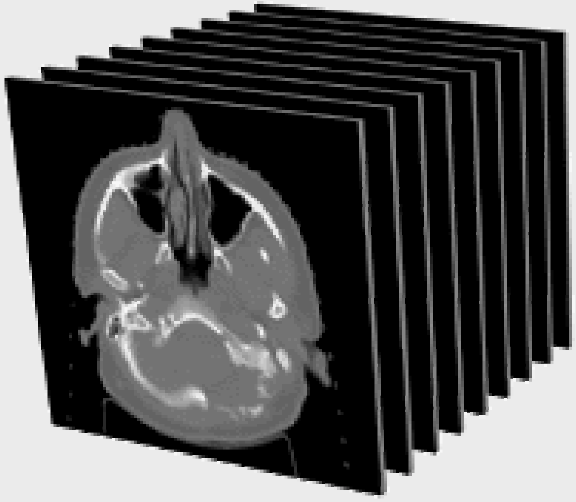
More and more treatment planning systems provide tools for computer-aided tumor segmentation. Two classes of segmentation algorithms can be defined:

- Semiautomatic segmentation algorithms
- Fully automated segmentation algorithms

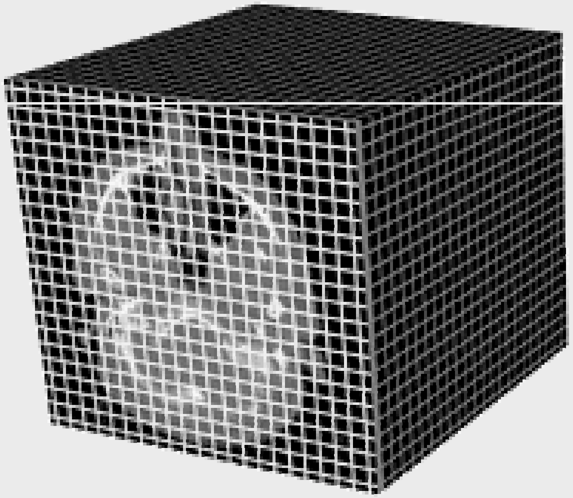
All segmentation algorithms can be divided into two groups of different approaches as to how to find a structure:

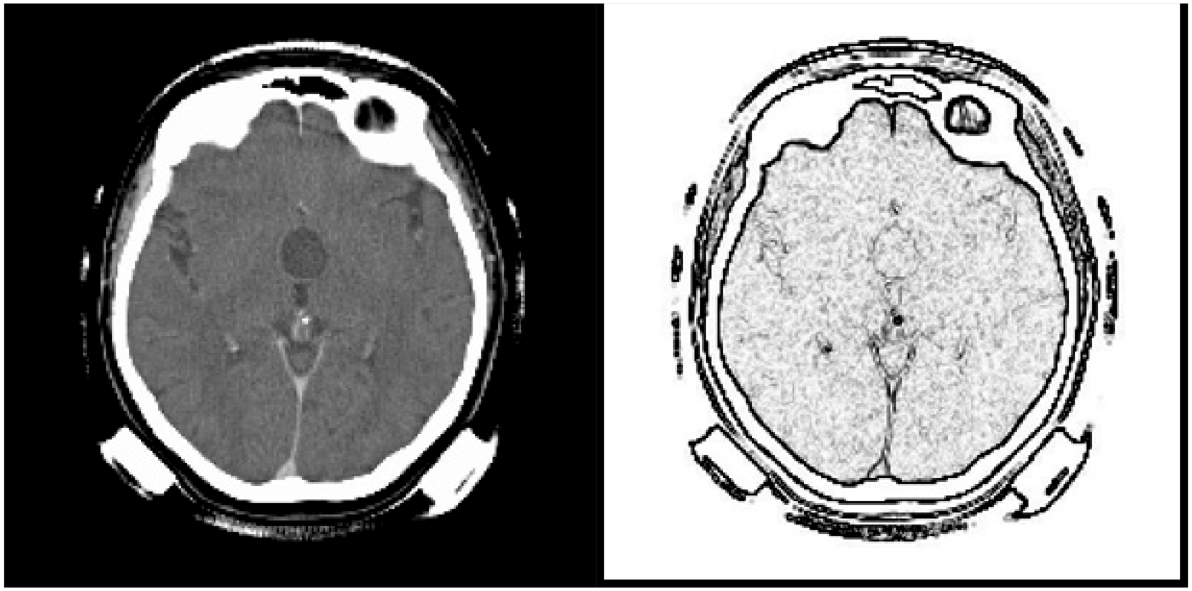
- Region-based approaches
- Edge detection algorithms

(a) CT-scan stack of patient



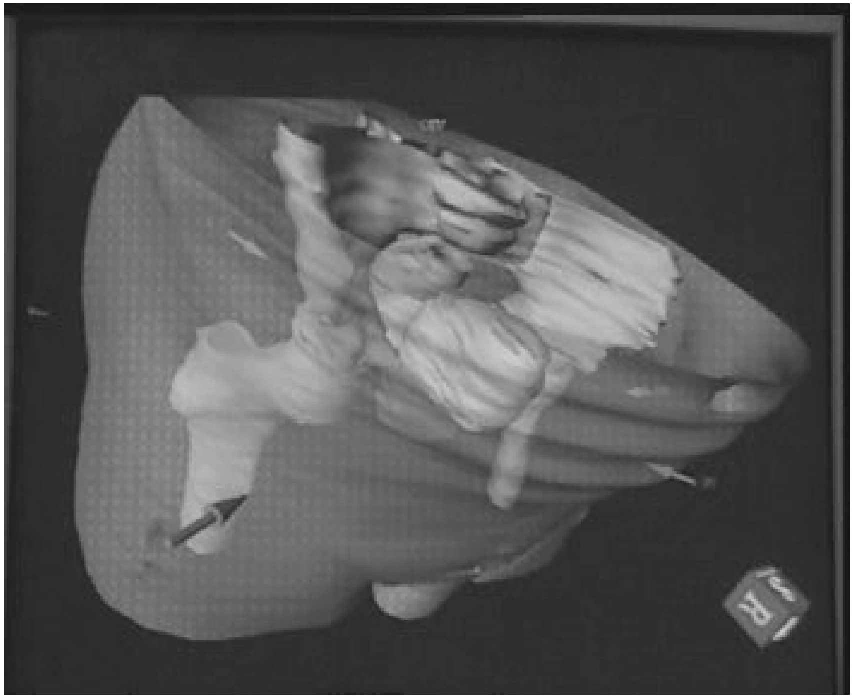
(b) Patient transport mesh





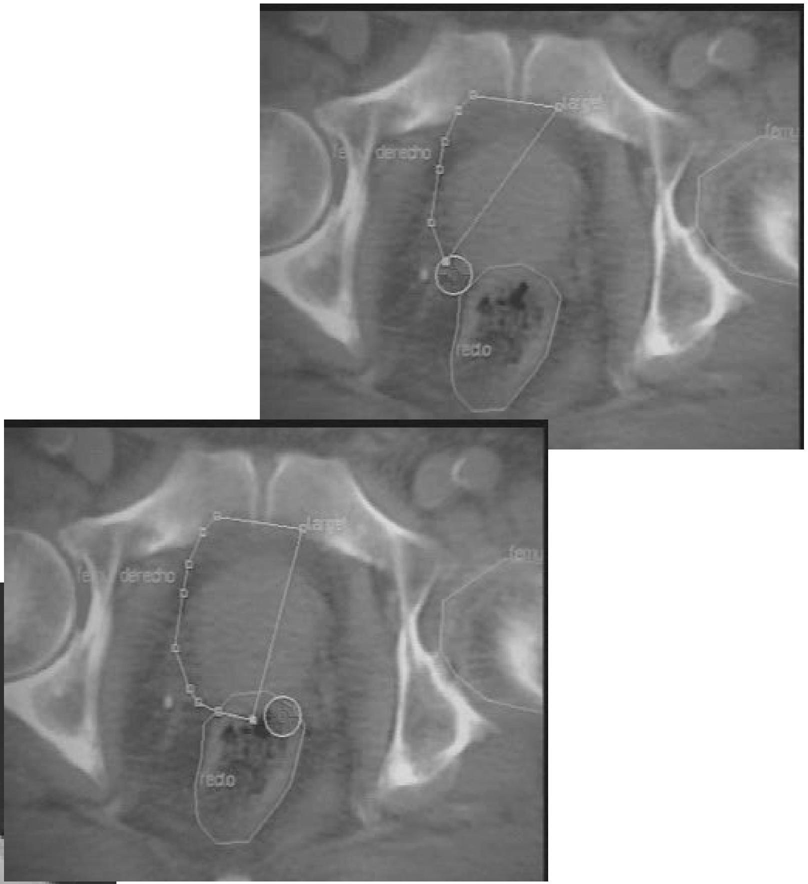
Gradient image of a CT image to distinguish different structures.

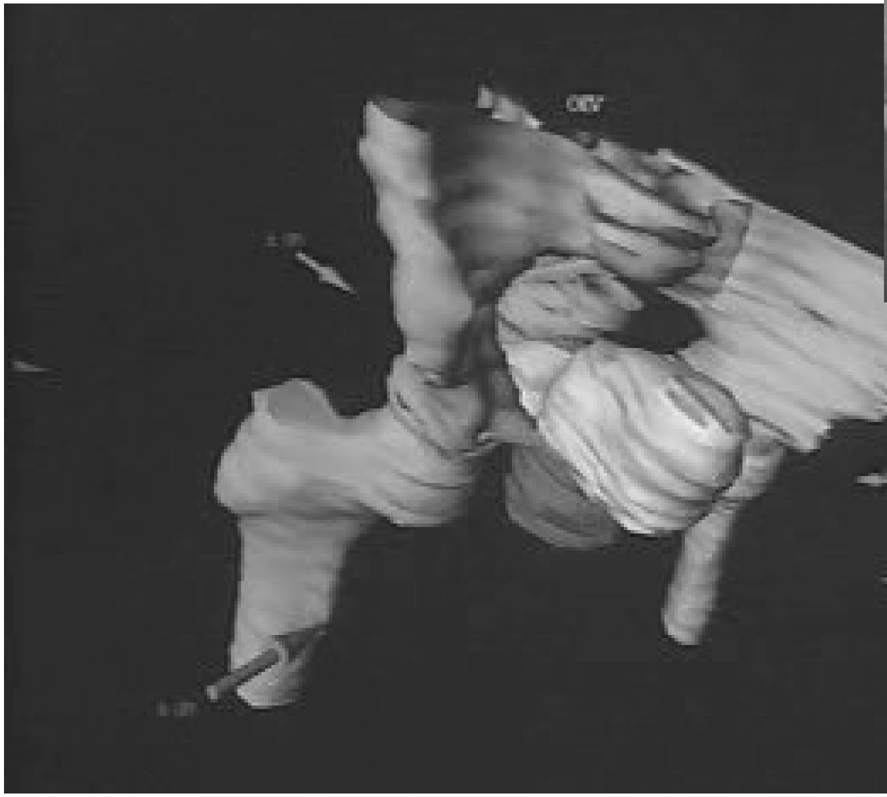
After a Full 3D reconstruction it is important to define different Volumes of Interest => see next slide



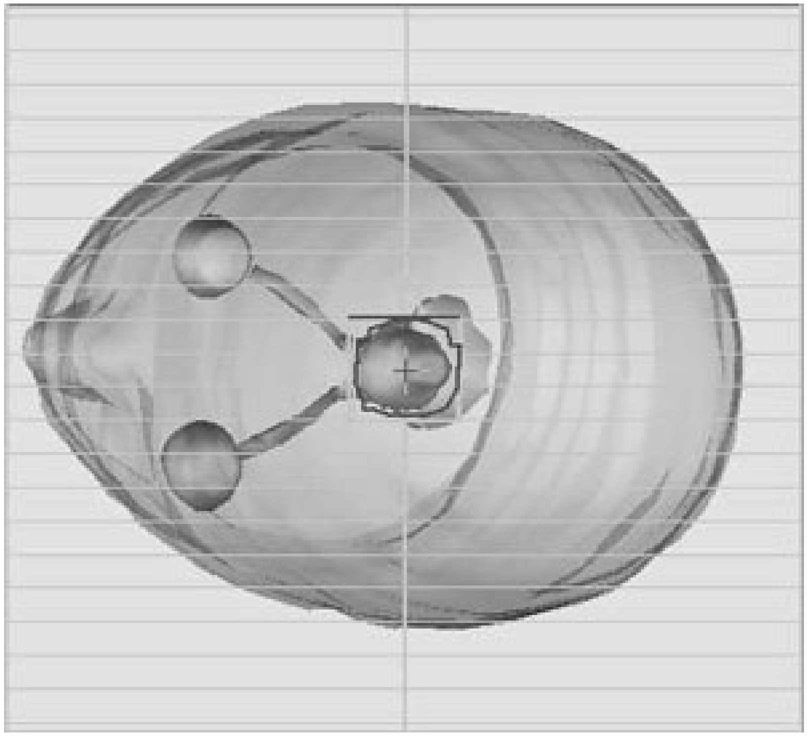
Definizione dei VOI (Volumes Of Interest)

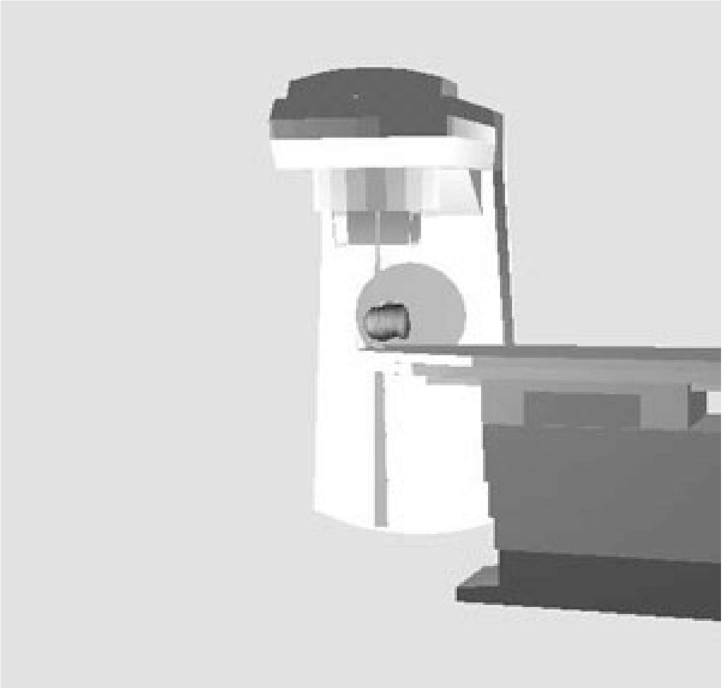
I contorni di diversi volumi di interesse e particolarmente de vomule tumorale, vengono definiti punto per punto su ogni sezione della TAC per poter definirli con precizione in 3D.

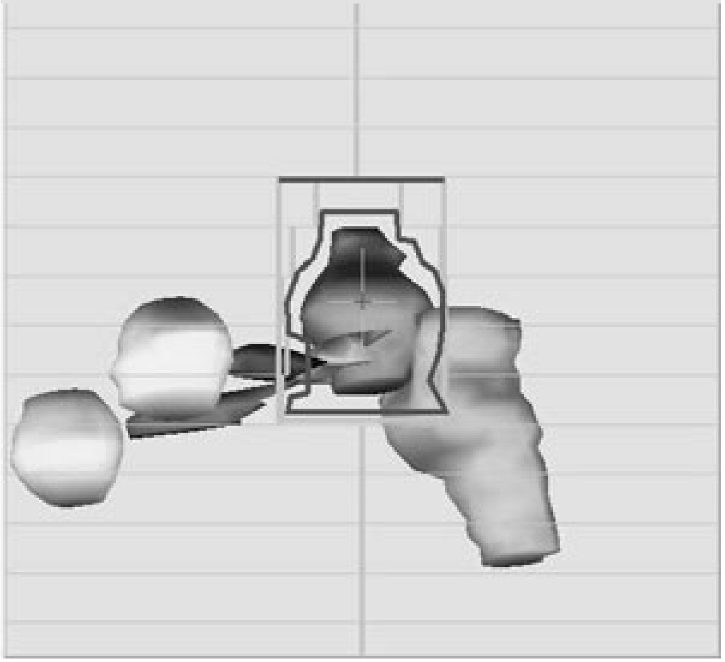




TP notion: BEV







Appropriate irradiation directions can be found interactively with the Beam's Eye View (BEV). In the BEV the therapist views the three-dimensional surface model from the position of the radiation source. In this way, it immediately becomes clear which structures are enclosed by the current beam. Subsequently they can use the BEV to adjust the shape of the beam to the form of the target volume.

To realize irregularshaped beam portals, special kind of collimators have been developed.

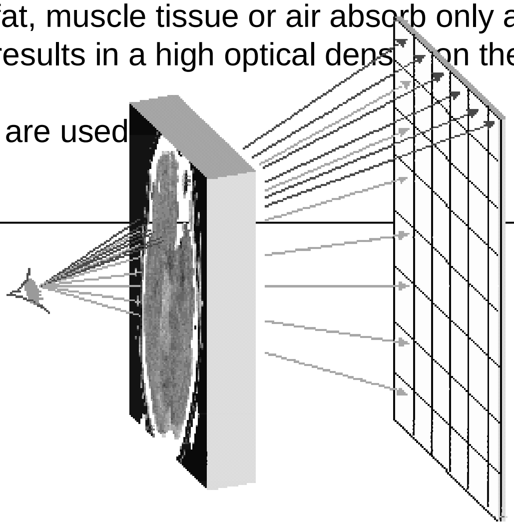
3D patient model

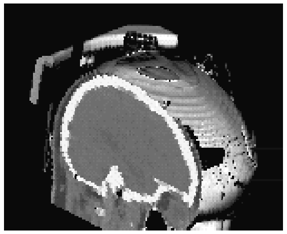
Recapitulation of the model built for the beam and the patient

Starting from the position of the radiation source, the algorithm traces a bundle of beams through an image cube, until a specified projection plane is reached (i.e., the film position).

To simulate therapy exactly, a computer program needs a precise description of an individual patient's anatomy. Mostly these models are based on image sequences, which are acquired with modern three-dimensional imaging devices (CT, MR, PET). The two-dimensional tomographs can then be combined to form a three-dimensional image cube by the planning program.<For three-dimensional radiotherapy planning, image sequences acquired with a CT scanner are of particular relevance. This imaging modality is robust, geometrically correct, and the intensity values allow the calculation of tissue density which is a pre-requisite for the exact calculation of the spatial dose distributions.
Based on CT image cubes, the behavior of real therapy simulators can be simulated on a computer. That means it is possible to generate artificial X-ray images, so called "Digital Reconstructed Radiographs" (DRRs), from arbitrary directions .

During image acquisition, X-Rays are absorbed differentially according to tissue density. Structures with high density (bones) absorb more of the intensity of the ray. That means, the intensity incident on the film is low, resulting in a low optical density on the film (bright). Water, fat, muscle tissue or air absorb only a small amount (or none) of the incident intensity. A higher intensity results in a high optical density on the film (dark or black).
To calculate such "artificial" images (DRRs), ray tracing algorithms are used.





Metodi di calcolo di un piano di trattamento ed ottimizzazione di dose

- ➩ Forward planning (see dose calculation)
- ➩ Monte Carlo simulation (see dose calculations)
- ➩ Inverse planning

❧mathematics and numerical tools for inverse planning

Big variety of algorithm already exciting:

- ❧Conjugate Gradient minimization.
- ❧Quasi Newton minimization.
- ❧Simulated annealing minimization.

All to resolve a simple linear system (see next slide).

Inverse planning

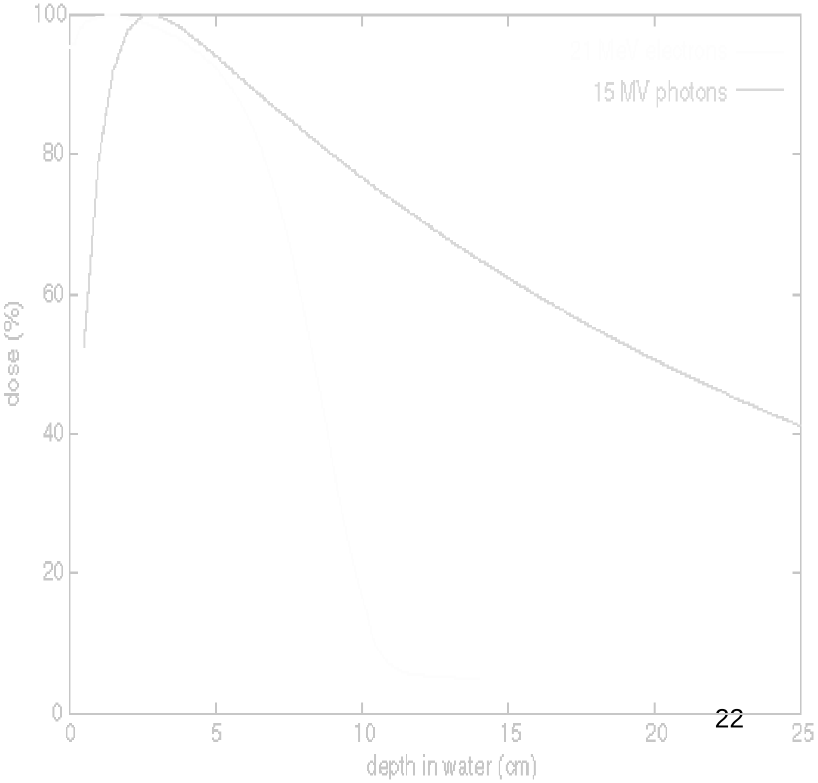
Problema generale per la determinazione della **dose nel voxel i,j,k**:

$$D_{i,\,j,\,k} = \sum_{n} f_n \times E^{(n)}_{i,j,k}$$

dove: $E^{(n)}_{i,j,k}$ energia depositata =>

$D_{i,j,k}$ dose prescritta dal medico (dose richiesta)

f_n fluenza del fascio n



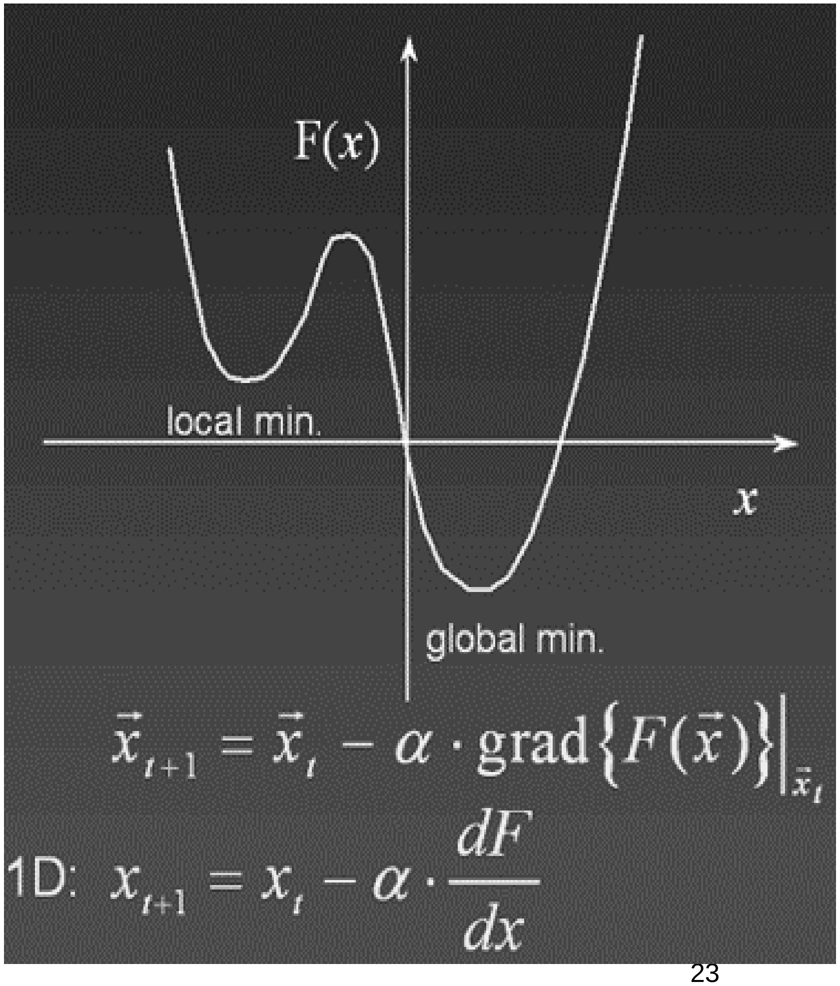
Il problema dell’ottimizzazione

=> Number of beams,

=> Radiation modality (photons, electrons),

=> Beam energy.

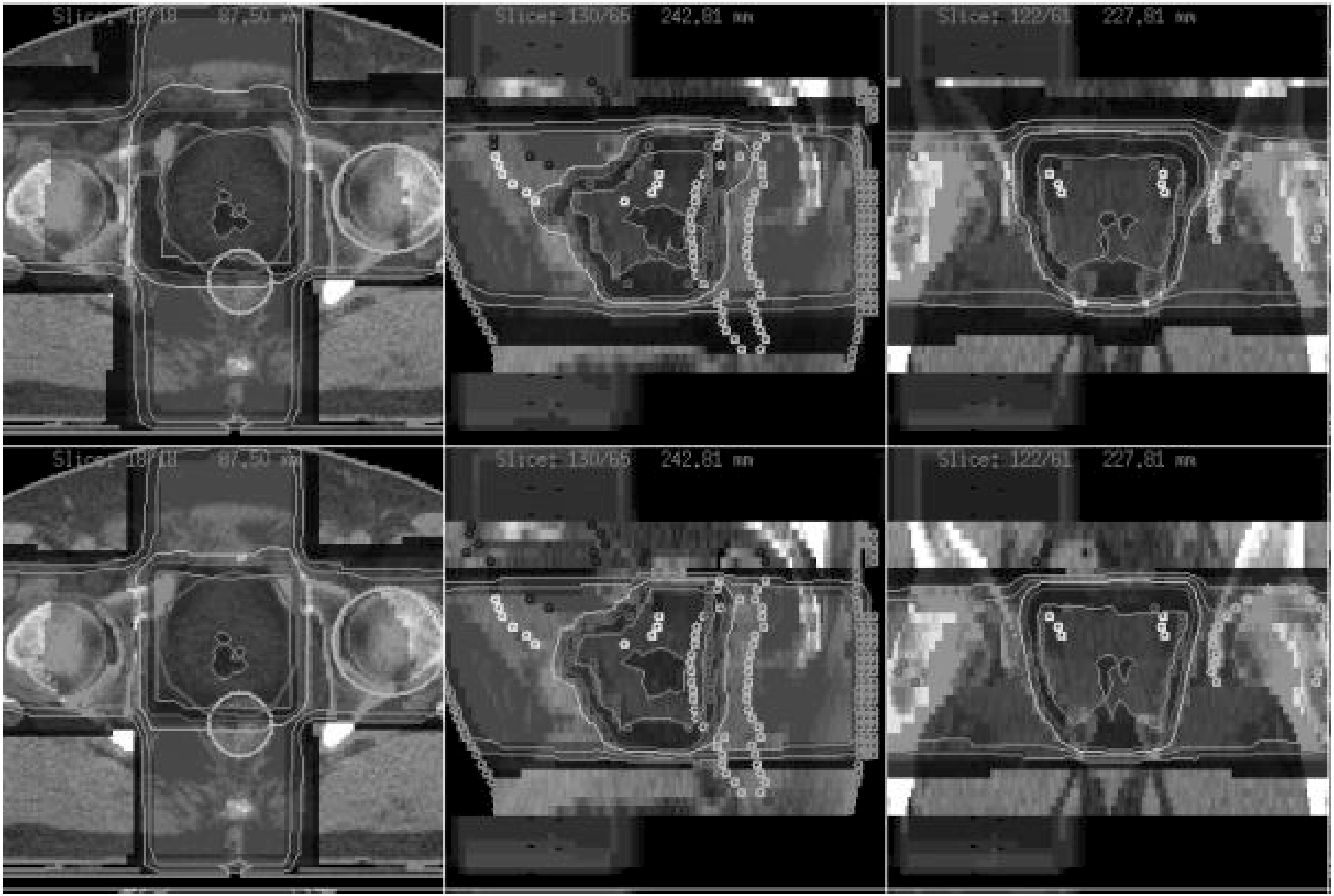
- Big variety of algorithm already exciting:
    - Conjugate Gradient minimization.
    - Quasi Newton minimization.
    - Simulated annealing minimization.



$$\vec{x}_{t+1} = \vec{x}_t - \alpha \cdot \text{grad}\left\{F(\vec{x})\right\}\Big|_{\vec{x}_t}$$

$$\text{1D:} \quad x_{t+1} = x_t - \alpha \cdot \frac{dF}{dx}$$

Confronto fra dose ottimizzata manualmente e dose ottimizzata con un algoritmo di 'inverse planning'.



Calcolo di dose finale

- **Metodo analitico**

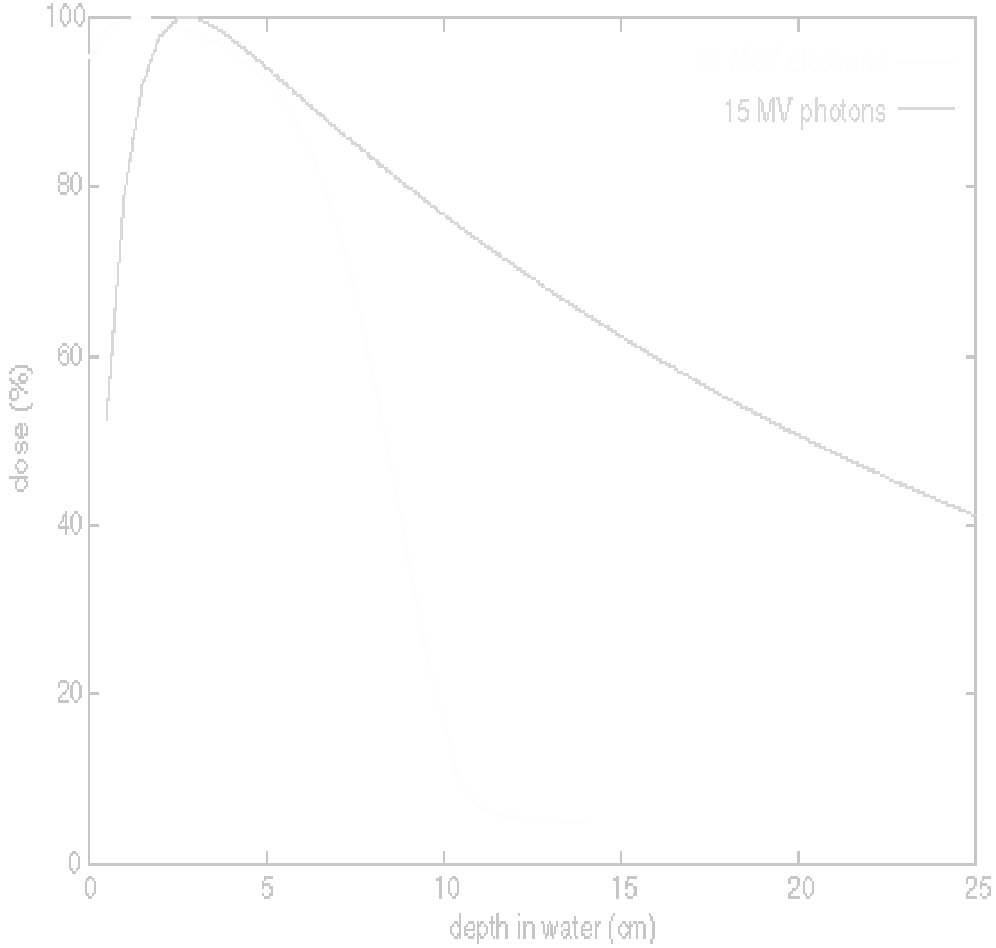
Modelli standard per fotoni:

Il modello detto fenomenologico e basato su una parametrisazione completa di sets di dati misurati di distribuzione di dose.=> dose in profondita per diverse energie, per di diversi dimensione di campo, profili laterali di dose, efetto dei collimarori....

Questo metodo a grandi inconveniente davante il problema di disomogeneità.

Modello del ‘pencil beam’ per elettroni:

I algorithmi sono simili a quelli per i fotoni, solo che per gli elettorni risolvere il problema di diffuzione necessita algoritmi piu fini. Il modello del ‘pencil beam’ e un modello che subdivide il fascio in una seria di singoli fascii elementari di 1-3 mm. Questo permette diincludere nei calcoli il fenomeno di diffuzione laterali dei fasci di eletttroni.



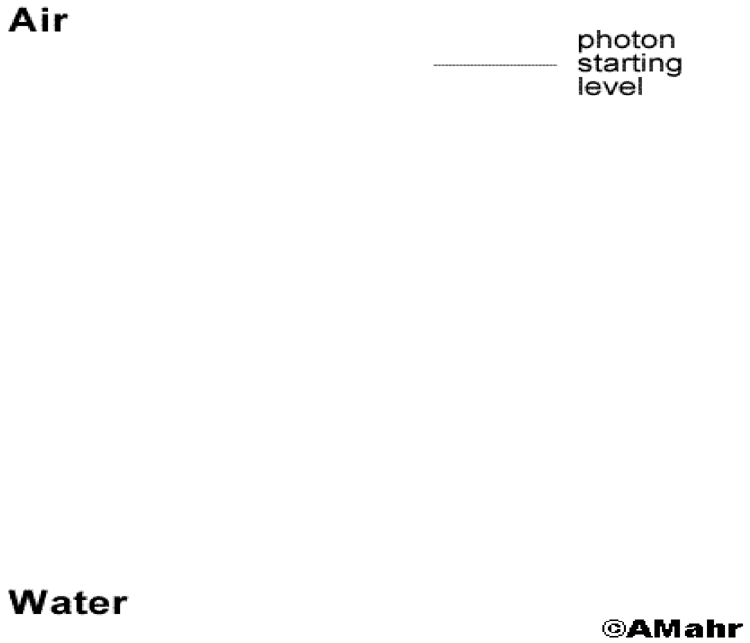
Tutte le caracteristiche di energia depositata in profondita di base sono prese in acqua.

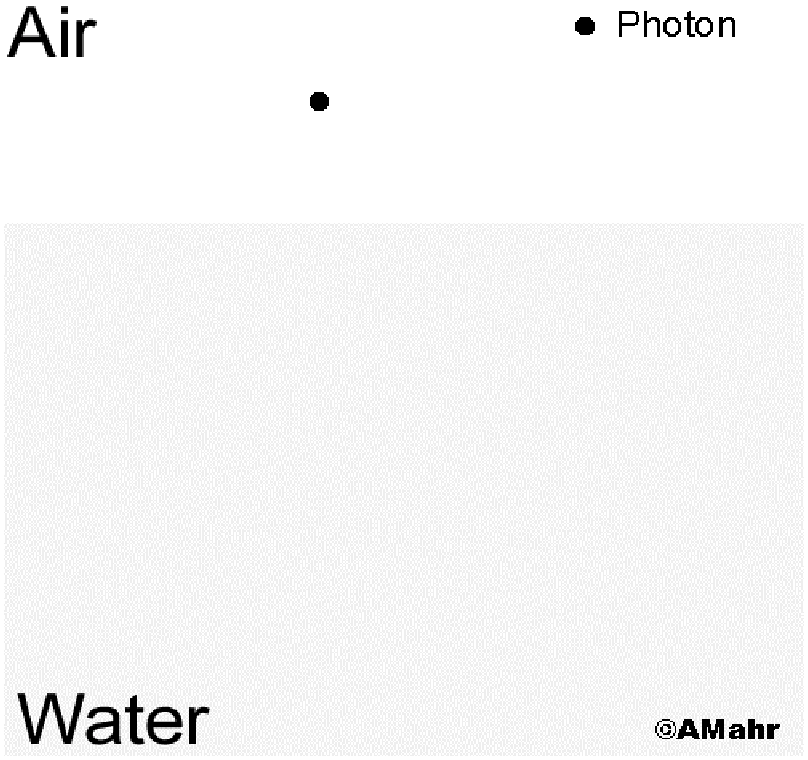
•Metodo MonteCarlo

Il metodo Monte Carlo permette di seguire i processi in scala microscopica. Tutti processi fisici di fotoni o elettroni vengono bene definiti. Il trasporto e la creazione delle particelle (fotoni e elettroni) sono simulati come processi stocastici nei punti di interazione.

Le disomogeneita del volume globale in cui viene ripresa nella simulazione. Questo permette una migliore estimazione del energia depositata e quindi della distribuzione di dose.

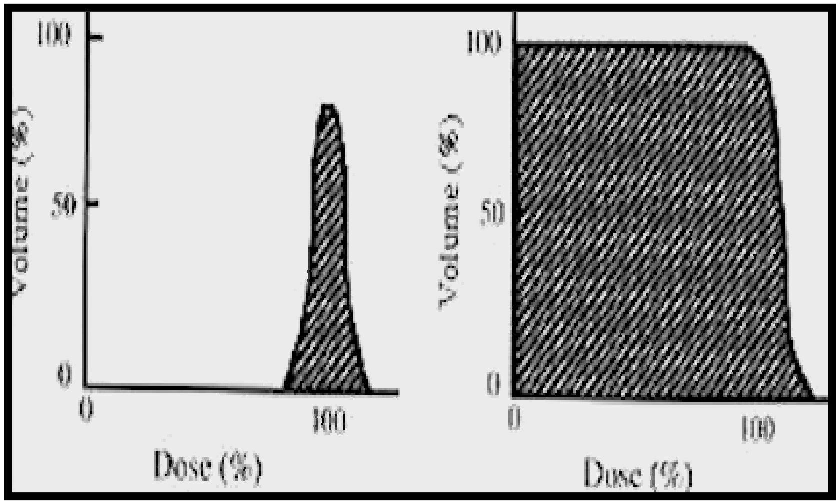
Il grande difetto delle Simulazione Monte Carlo e che sono molto lunghe e questo e esclude completamente un eventuale uso nella routine per il calcolo dei piani di trattamento.
L’utilita vera della MC rimane nella verifica e nell campo sperimentale.

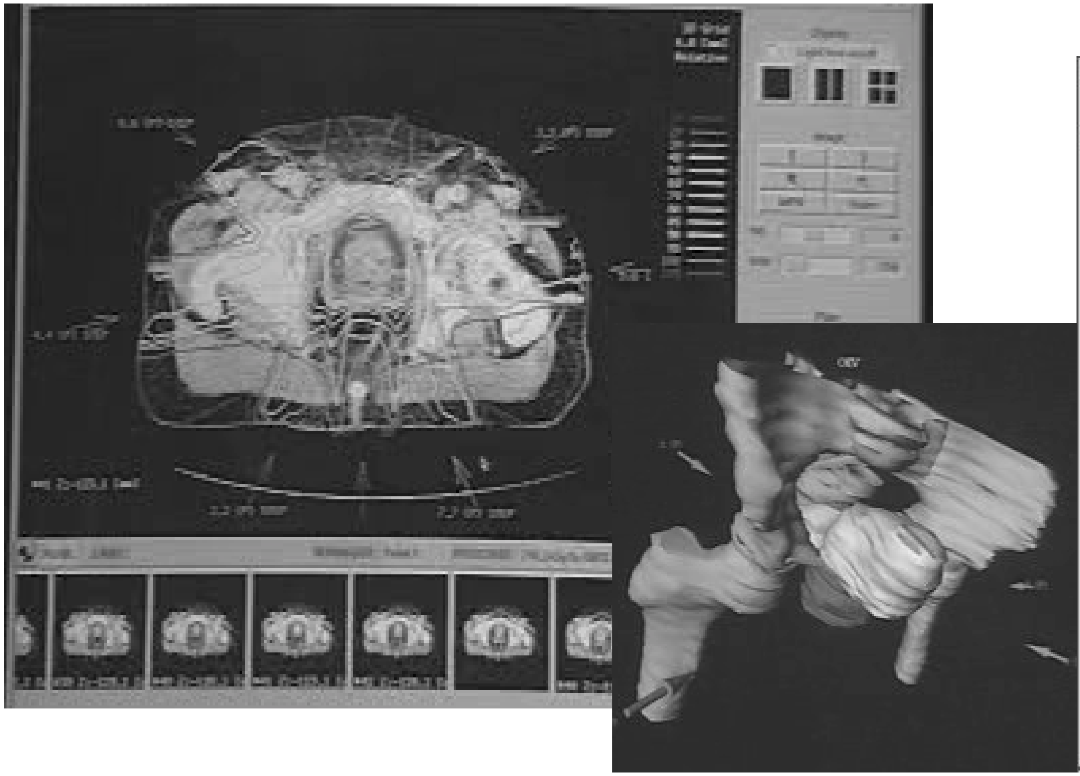


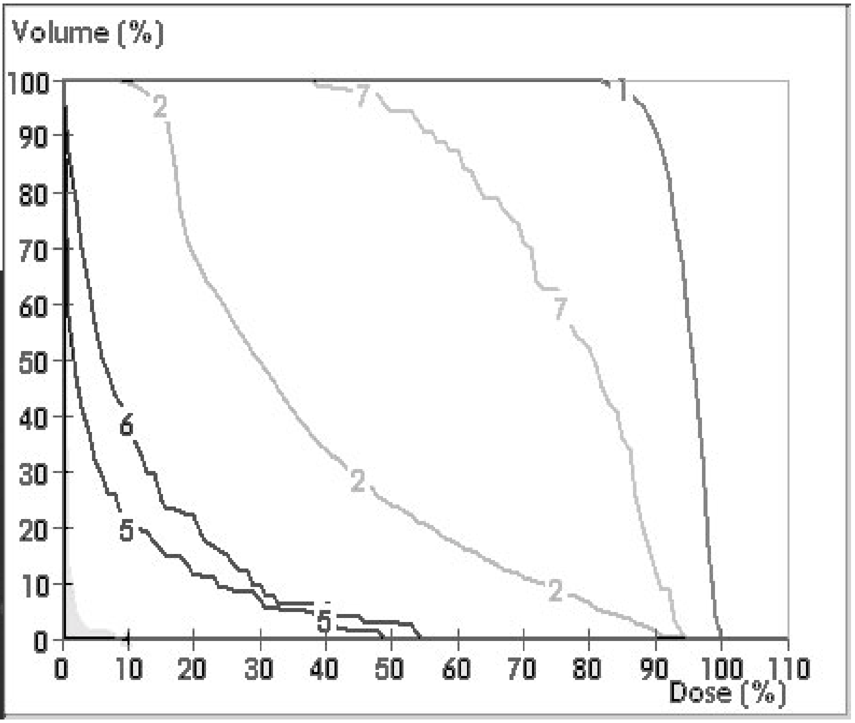


Valutazione 3D e Istogrammi dose-Volume (DVH)

- DVH diferenziale
- DVH cumulativo







Curve di isodose di un campo singolo
SSD e SAD

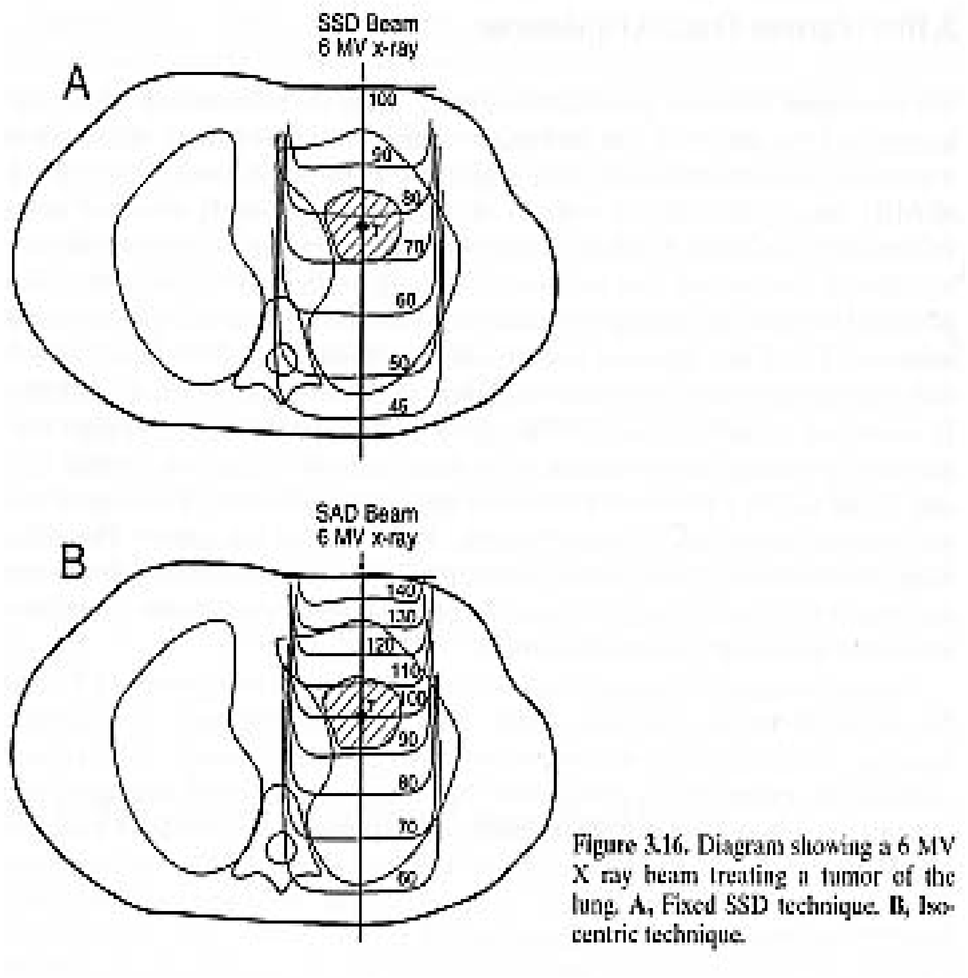


Figure 3.16. Diagram showing a 6 MV X ray beam treating a tumor of the lung. A, Fixed SSD technique. B, Isocentric technique.

Variazione della dose nel volume trattato: ~20%

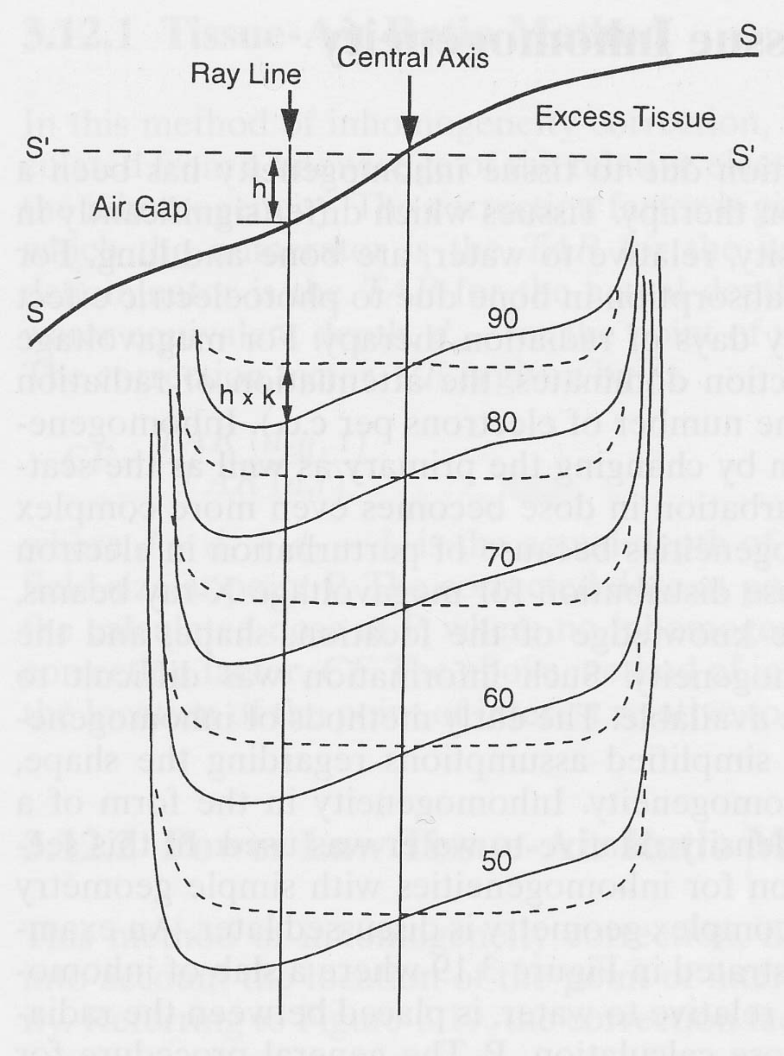
Dose a d_m ~45% della dose al tumore: per dare

60 Gy al tumore la pelle riceve 86 Gy, al di sopra

del limite accettabile.

Problemi con la dose agli OAR: midollo spinale.

Angolo di incidenza del fascio, irregolarita' della superficie, disomogeneita'



Problem of disomog. 830

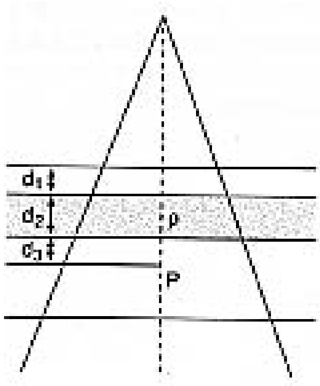


Figure 3.19. Diagram showing a water equivalent phantom containing an inhomogeneity of electron density ρ relative to that of water. P is the point of dose calculation.

Curve di isodose – due campi contrapposti SSD e SAD

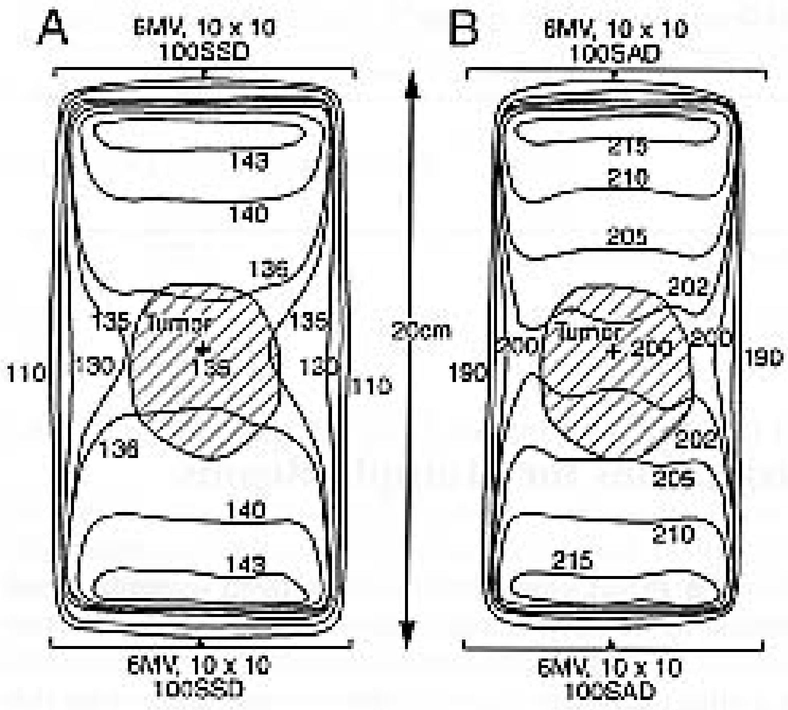


Figure 3.20. Composite isodose distribution for a pair of parallel opposed fields. A, Each beam is given a weight of 100 at the depth of d_m. B, Isocentric plan with each beam weighted 100 at the isocenter.

Curve di isodose – Campi multipli

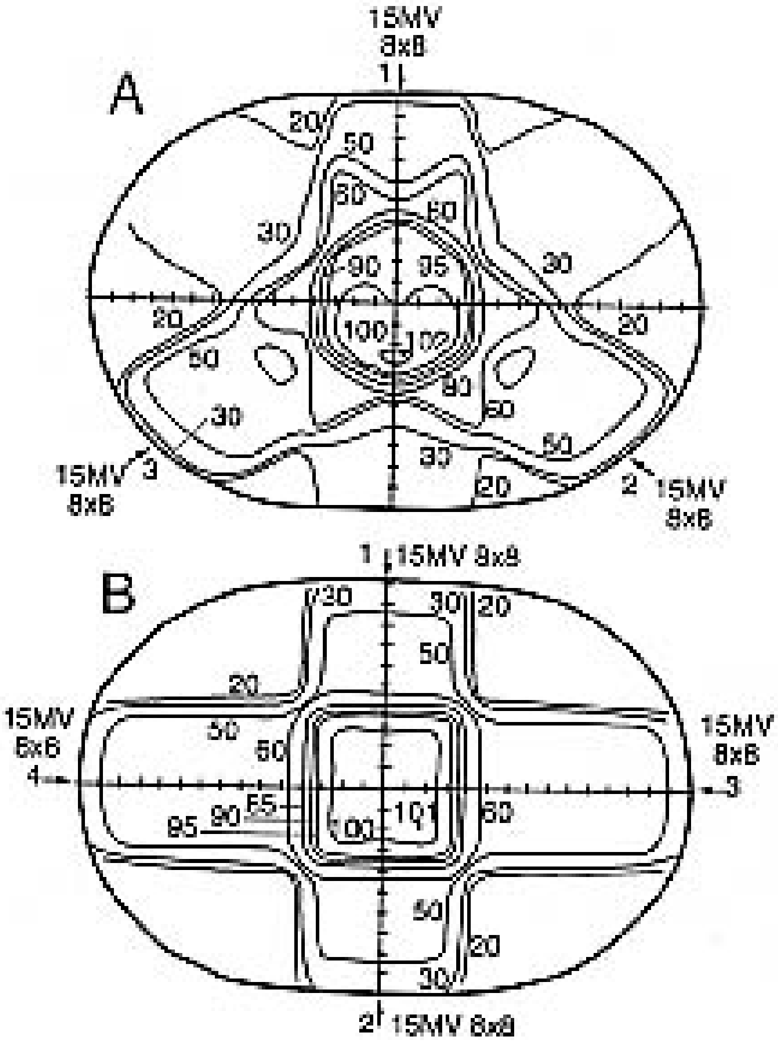
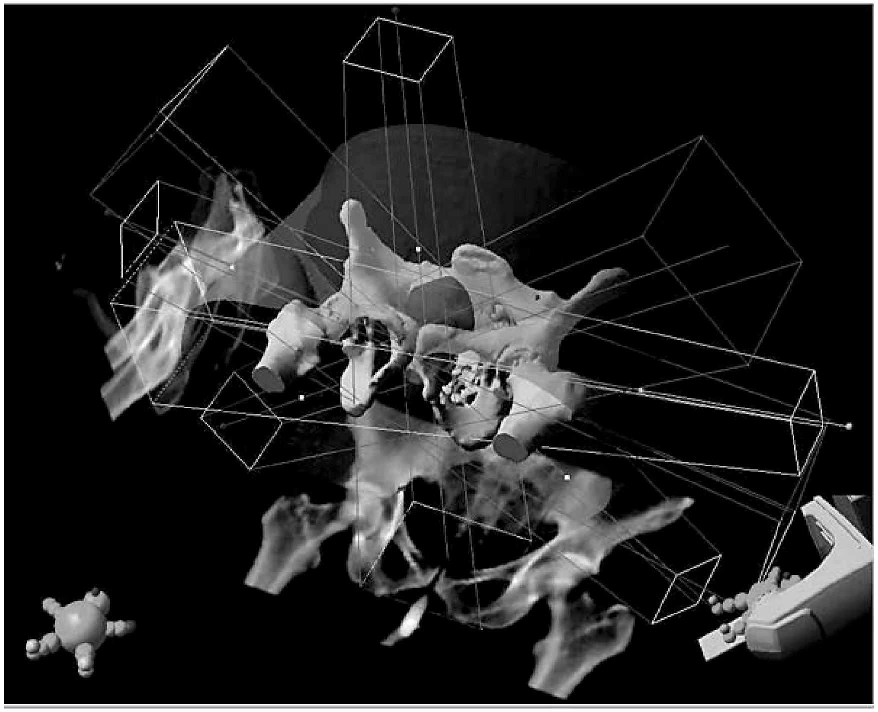


Figure 3.23. Examples of multiple field plans. **A.** Three-field isocentric technique. Each beam delivers 100/3 units of dose at the isocenter; 15 MV, field size = 8 × 8 cm at isocenter, *SAD* = 100 cm. **B**, Four-field isocentric technique. Each beam delivers 25 units of dose at the isocenter; 15 MV, field size = 8 × 8 cm at isocenter, *SAD* = 100 cm.



Irradiazione con elettroni - cenni

Energia media alla superficie:

$$\overline{E_0} = (2.33MeV/cm)R_{50}$$

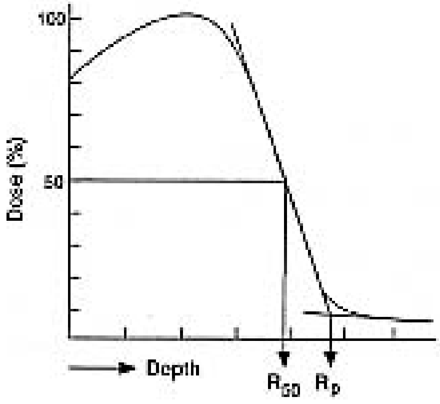


Figure 3.31. Diagram showing the depth of 50% dose, R_{50}. Also depicted is the depth of practical range, R_p.

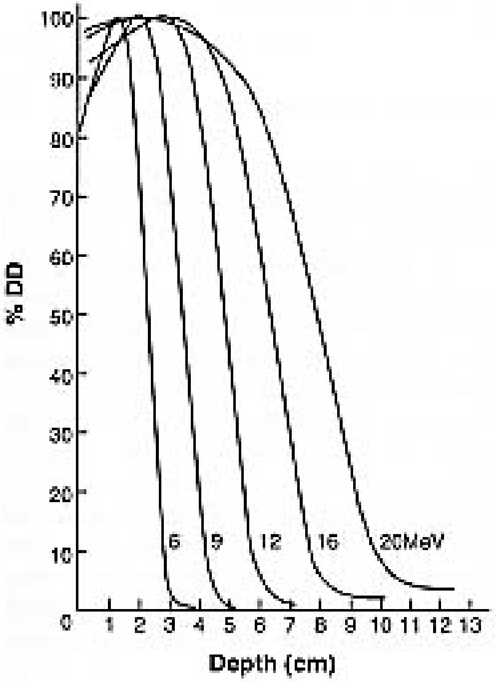


Figure 3.32. Central axis depth dose curves of 6, 9, 12, 16 and 20 MeV electron beams. The depth dose falls off sharply, particularly at the lower energies, and the surface dose increases with increasing energy.

Curve di isodose – elettroni

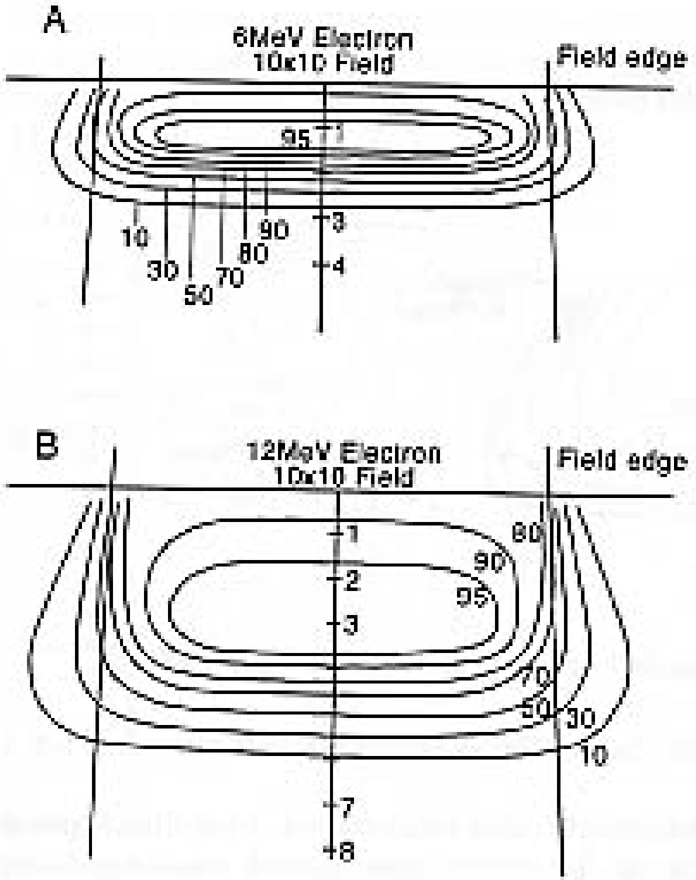


Figure 3.33. Electron beam isodose curves. (A) 6 MeV 10 × 10 cone. The 80% curve is at 1.8 cm. There is little radiation beyond 3 cm. (B) 12 MeV 10 × 10 cone. The 80% curve is at 4.2 cm. Note that the 80% isodose line is not flat at the geometric edge of the field. A generous field must be used.

Disomogeneita’ - elettroni

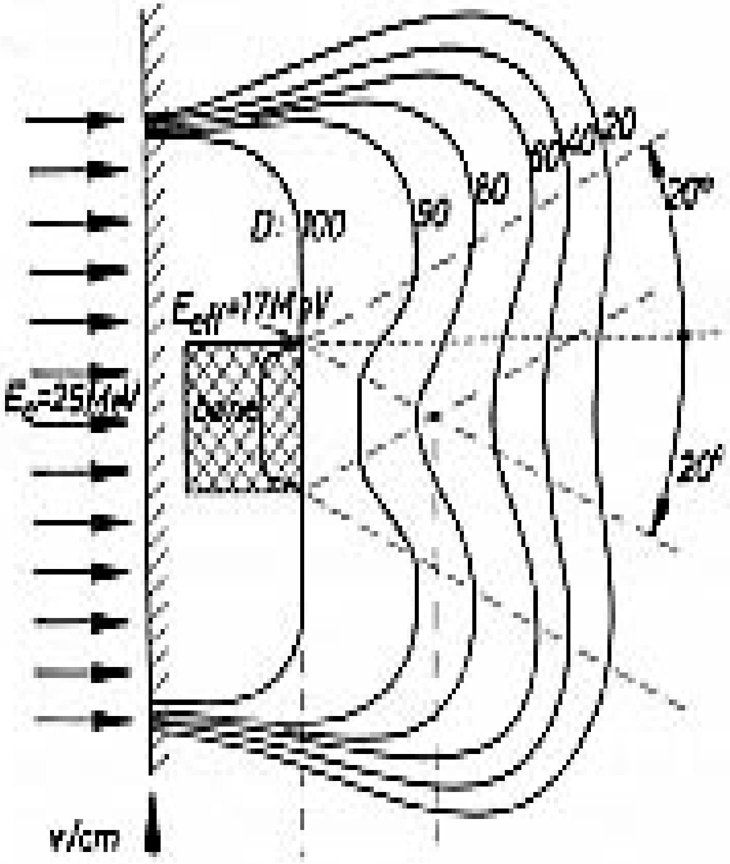


Figure 3.35. Dose perturbation due to bone inhomogeneity. (Pohlit W. Ann NY Acad. Sci., 1964: 161: 189. Used with permission.)

Trattamento - elettroni

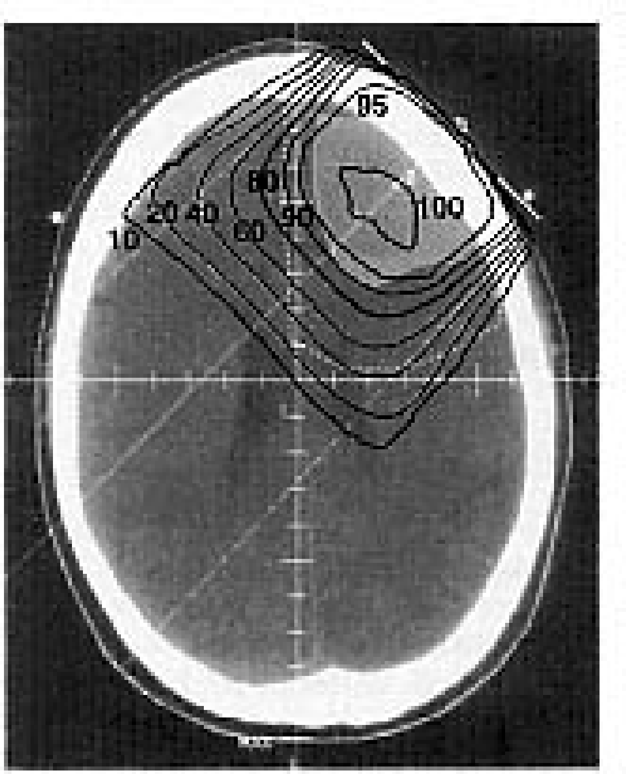


Figure 3.36. Picture illustrating the application of CT scan in treatment planning with an electron beam. Beam energy and field size is selected based on tumor volume and bone thickness and its density relative to water.

References

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