Imaging in radiotherapy patient data acquisition

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An idealistic picture showing a treatment with external radiation
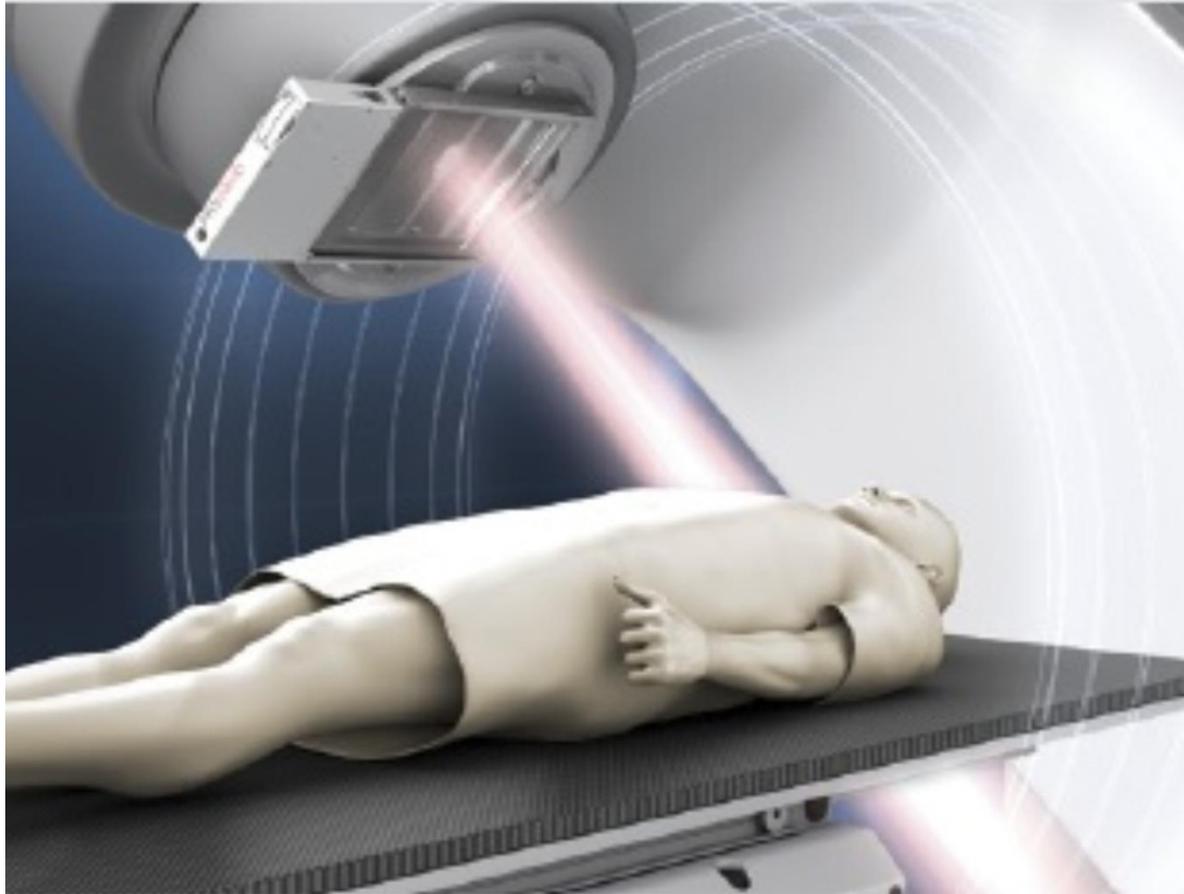
The problem of seeing neither the tumor nor the radiation

This lesson is partly based on:

Radiation Oncology Physics:
A Handbook for Teachers and Students

E.B. Podgorsak
Technical Editor

Sponsored by the IAEA and endorsed by the COMP/CCPM, EFOMP, ESTRO, IOMP, PAHO and WHO
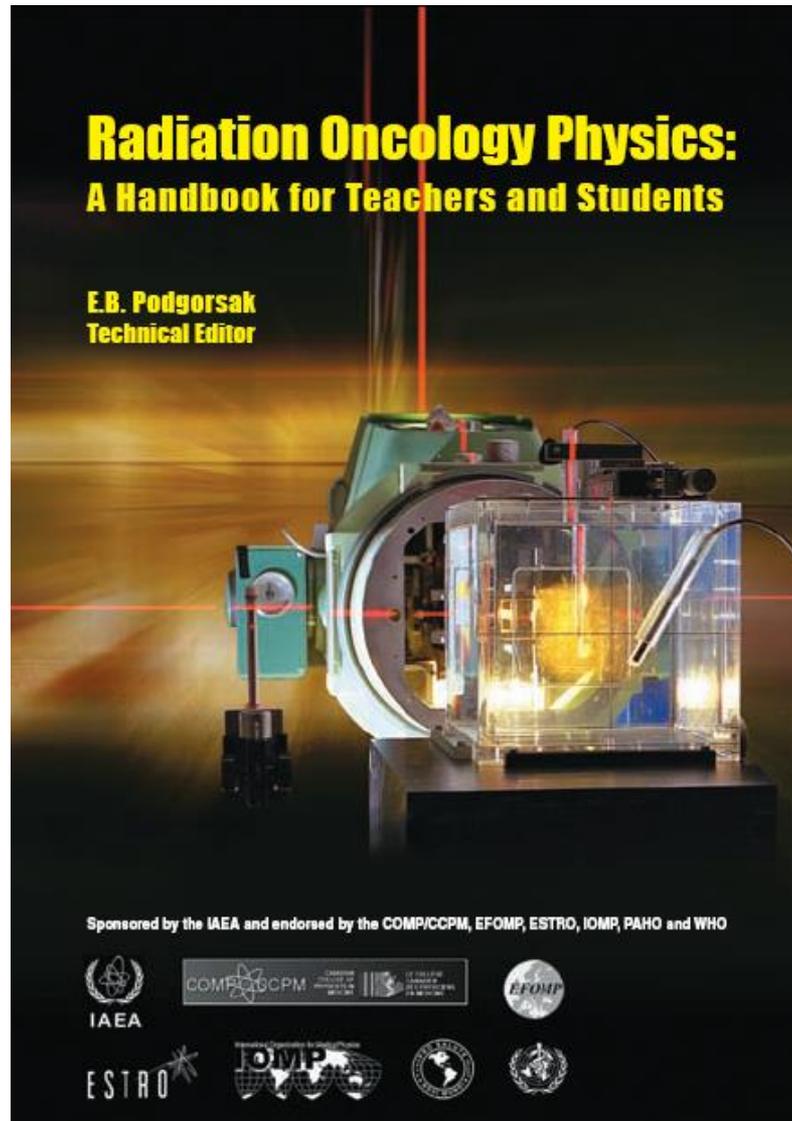
.… And also partly based on:

3D Conformal Radiation Therapy

A multimedia introduction to methods and techniques
2nd revised and enhanced edition

Springer

Content:

1. Introduction: Need for and types of patient data

2. Segmentation methods

3. Image registration

4. Display of Registered Image Sequences:
   Image Fusion

5. Patient treatment position and immobilization devices

6. Conventional treatment simulation

7. Computed tomography-based simulation

8. Conventional simulator vs. CT simulator

9. Magnetic resonance imaging for treatment planning

Need for patient data

Within the treatment simulation and calculation process, the patient anatomy and tumor targets have to be represented by a **model for the patient**.
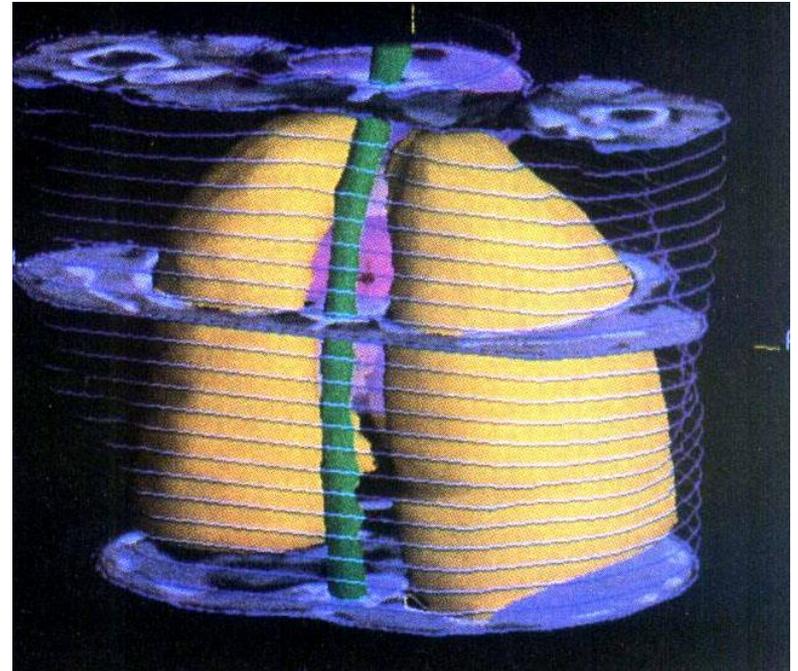
Nowadays such a model is a three-dimensional model.

Example:

CTV: Mediastinum (violet)

OAR:

- Both lungs (yellow)
- Spinal cord (green)

Some general considerations on patient data:

- **Patient dimensions** are always required for treatment time or monitor unit calculations, whether obtained with a caliper (very old-fashioned) or from CT slices.

- The amount of required patient data depends on:
    - The treatment planning method/system
    - the dose calculation method

- For patient positioning, additional information may be required, such as landmarks (anatomical, artificial) or other items (breathing sensor etc).,.

1. Type of patient data

The patient information required for treatment planning varies from rudimentary to very complex data acquisition:
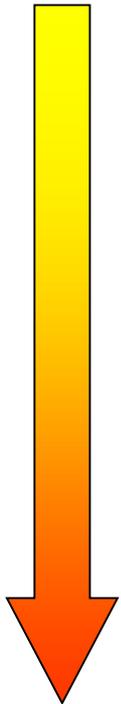
- Distances read on the skin.

- Manual determination of contours.

- Acquisition of CT information over a large volume.

- Image fusion (also referred to as image co-registration) using various imaging modalities, such as CT, MRI, and PET.

- Advanced methods in IGRT

Type of patient data

Data for 2D treatment planning

A single patient contour, acquired using lead wire or plaster strips, is transcribed onto a sheet of graph paper, with reference points identified.

Type of patient data
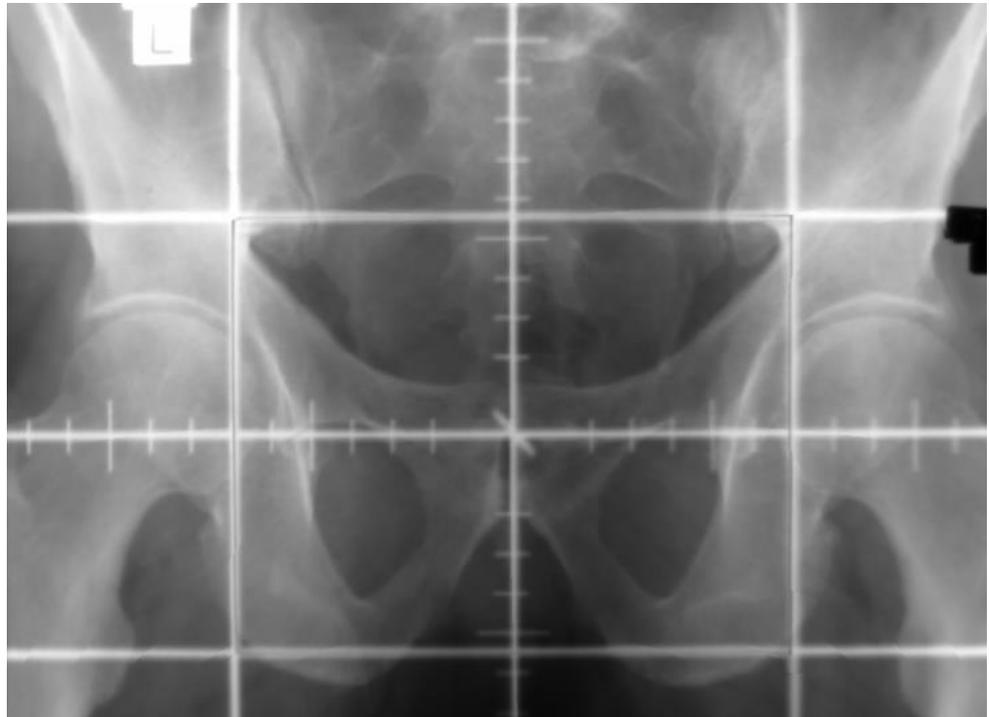
Data for 2D treatment planning

Radiographs taken with a simulator:

Reference simulator film (kV)

They can be taken for comparison with port films during treatment.

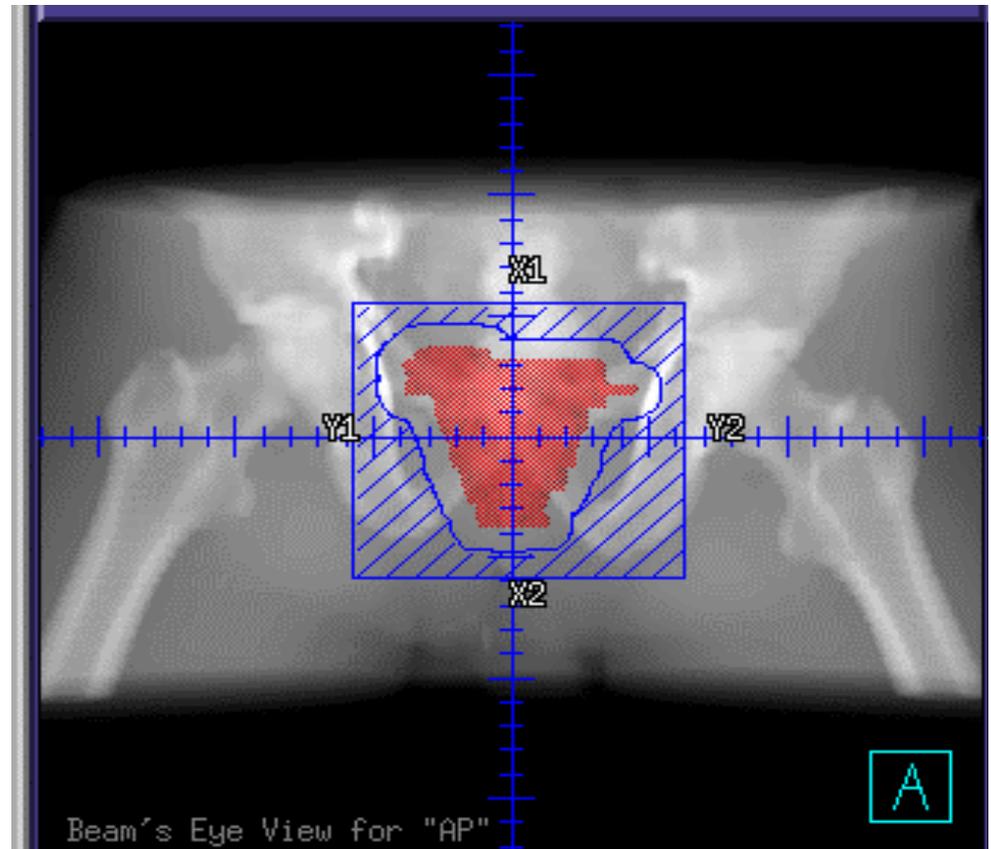But remember the talk of yesterday: a transfer error is always involved!

Data for 2D treatment planning

Radiographs are in particular helpful for irregular fields:

- **for block shaping**

- **for positioning**

Beam's Eye View for "AP"

Images and image processing for modern 3D treatment planning

- Data are usually based on CT images.

  - suitable slice spacing?

  - 0.5 - 1 cm for thorax

  - 0.5 cm for pelvis

  - 0.3 cm for head and neck.

- Structures relevant for the radiation treatment can now be identified on the CT slices.

The following image processing procedures applied to anatomical structures are typical CT based procedures:

- The process of distinguishing structures or volumes from the background by drawing contours is called **segmentation**.

- The process of matching images obtained from different imaging devices is called **image registration**

The segmentation process in particular refers to the well known "ICRU volumes" that have been defined as principal volumes related to three-dimensional treatment planning.

- The **Gross Tumor Volume** (GTV), because
    - For the purposes of diagnosis and staging
    - The GTV is the most important indicator for measuring tumor remissions and therefore for measuring therapy success
    - The GTV represents that volume which **has to be irradiated** to achieve local tumor control

- The **Clinical Target Volume** (CTV)

- The **Planning Target Volume** (PTV)
  Based on the PTV, alternative treatment plans can be evaluated and treatment decisions can be made.
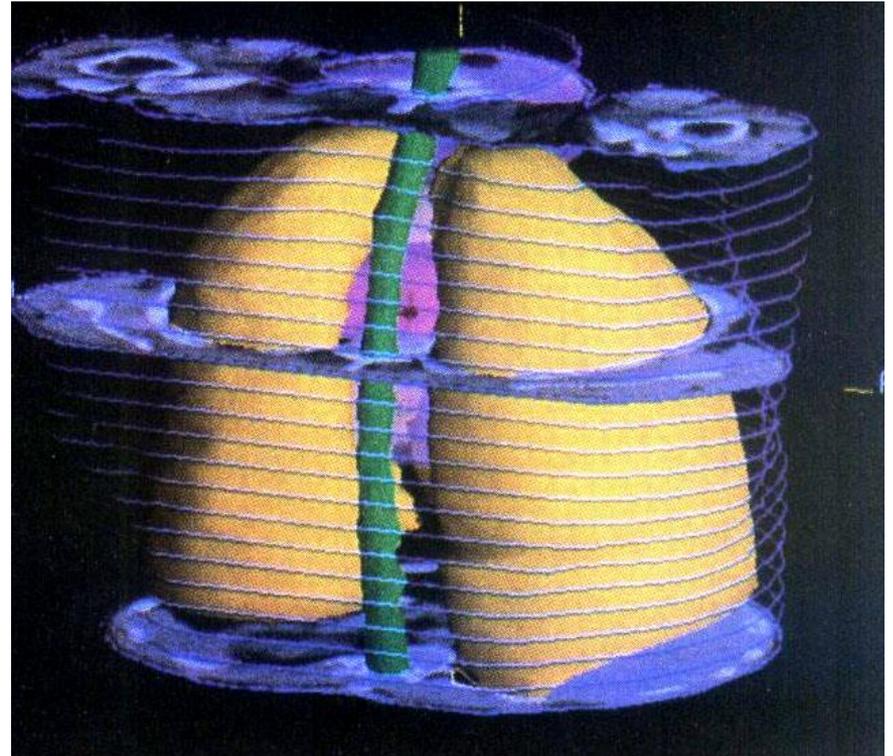
Example:

Segmentation of the tumor, organs at risk and patient contour for the treatment of a brain tumor.
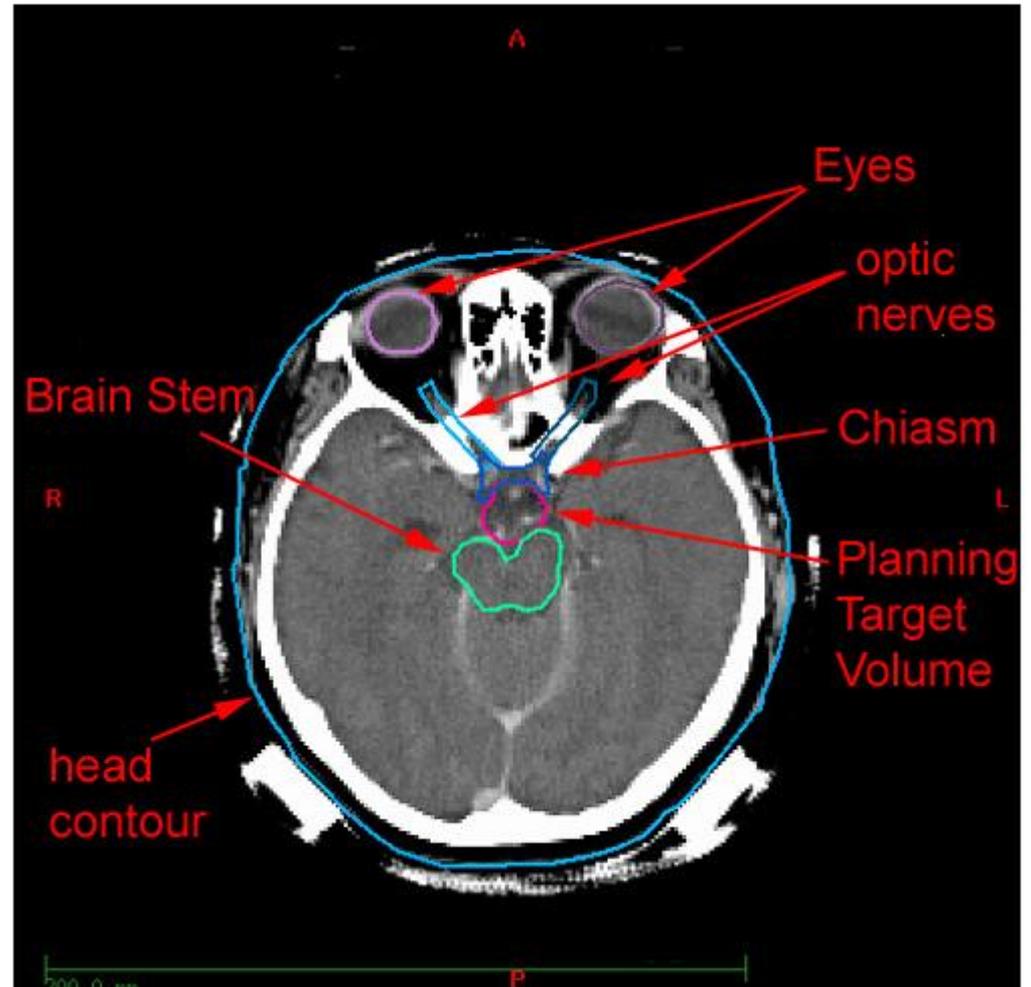
Example:

3D segmentation of the tumor, organs at risk and patient.

Segmentation algorithms

All segmentation algorithms can be divided into two groups:

1) Region-based approaches:

Region-based approaches try to find an area of pixels with **similar properties** (e.g., gray values).

The border between the volume of interest and background is thus defined by a cut-off value of possible values of the pixels (e.g. HU values).

This cut-off value is either determined by the

algorithm (fully automated algorithms) or

by the user (semiautomatic algorithms).
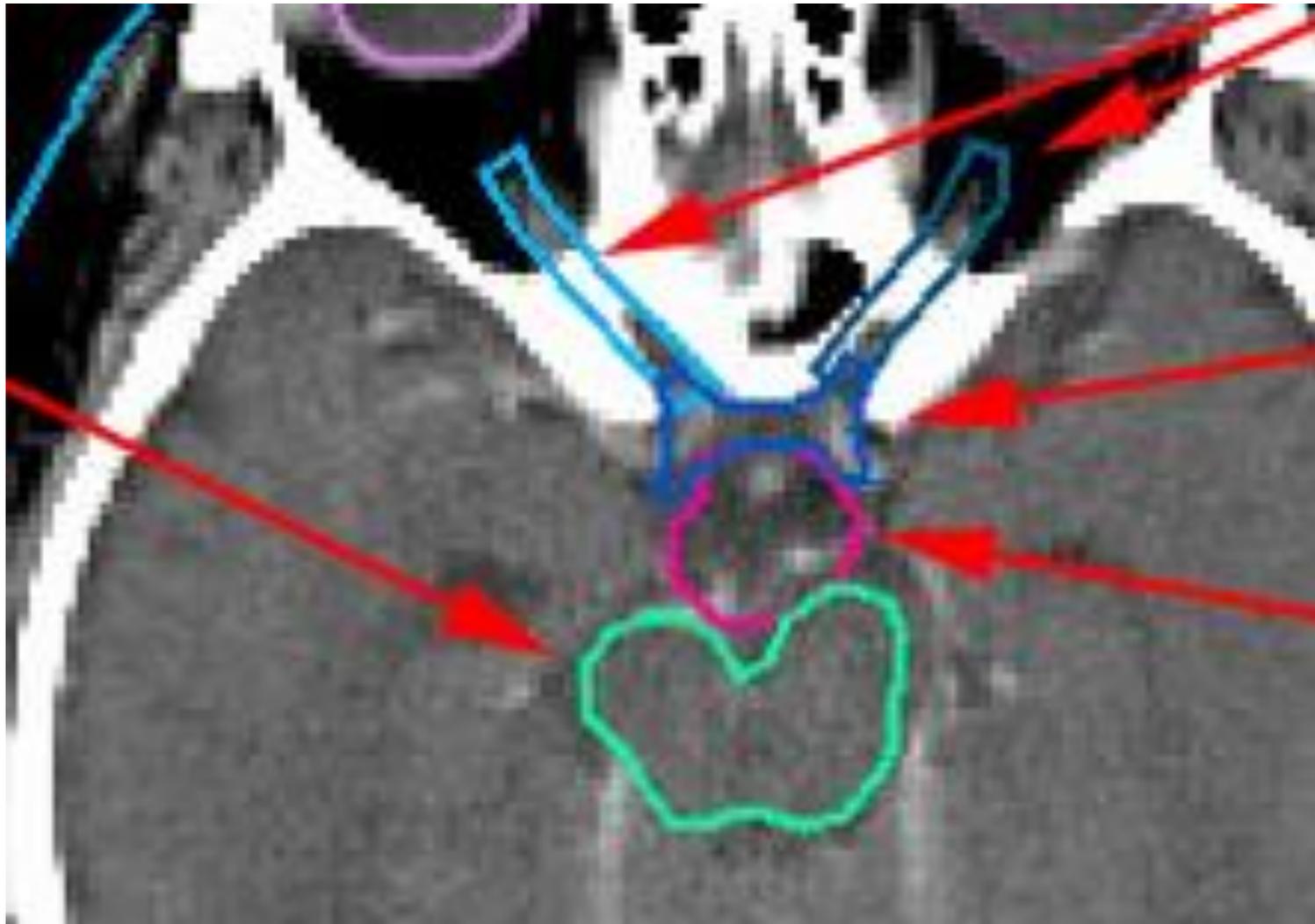
CTV

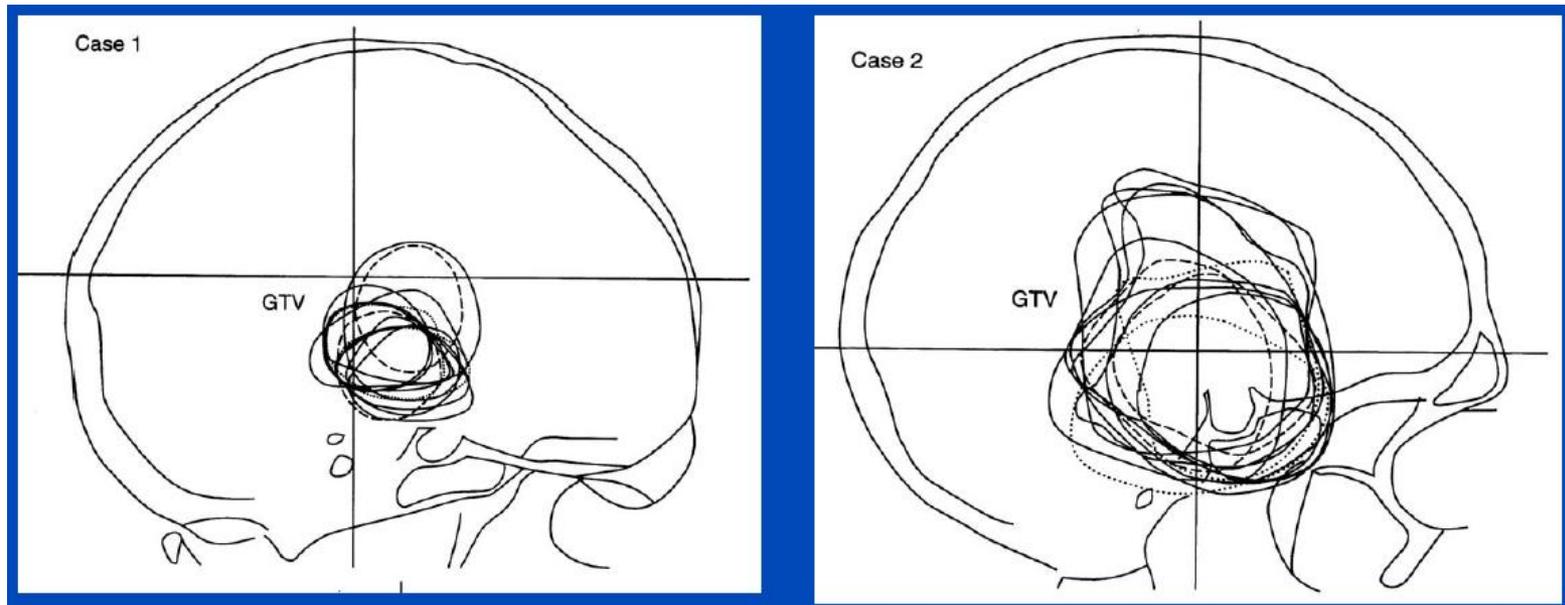However, even using the same technique, inter-observer variations may be significant.

Example: a lateral radiograph used for GTV definition (brain tumor)
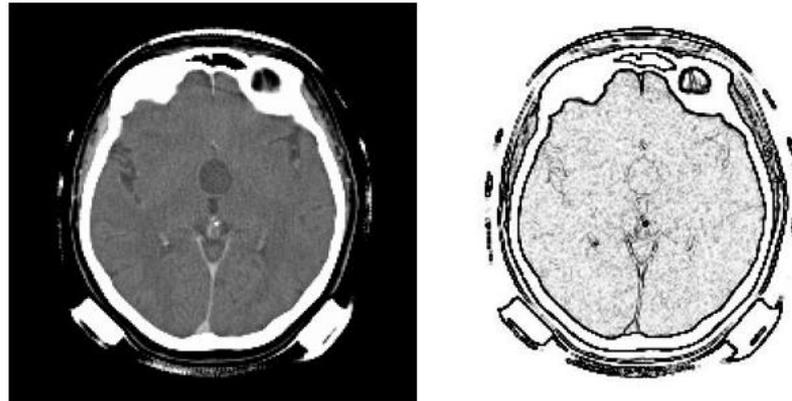

8 radiation oncologists ———— , 2 radiodiagnosticians ··········, 2 neurosurgeons - - - - - - -

Segmentation methods

2) Edge detection algorithms

They look for sudden changes in a particular parameter. Simple examples of edge detection are gradient images:

By defining a cut-off value for the height of the parameter change, the number of edges found is increased or decreased.

Advantages and disadvantages of segmentation methods

	Manual segmentation	Semiautomatic segmentation	Fully automated segmentation
Speed	-		
Reproducibility	-		
Availability	++		

++ very good, + good, - poor, -- very poor

Image registration

Modern three-dimensional treatment planning is based on tomographic images of **different** modalities:

- **X-Ray computed tomography** is the most important image modality since it is robust and the measured tissue densities are the basis for the calculation of dose distributions.

- **MRI Images** display soft tissue with considerably better contrast which allow a more precise differentiation of tissue

- **PET** (positron emission tomography), **SPECT** (single photon emission computed tomography) and **MRS** (magnetic resonance spectroscopy) provide functional information such as metabolism and perfusion.

Image registration

To be able to use several image modalities **simultaneously,** it is necessary to establish a quantitative relation between the picture elements (pixels) of the different images.

Mathematical methods that are able to calculate and establish these relations are called **registration**, matching or image correlation techniques.
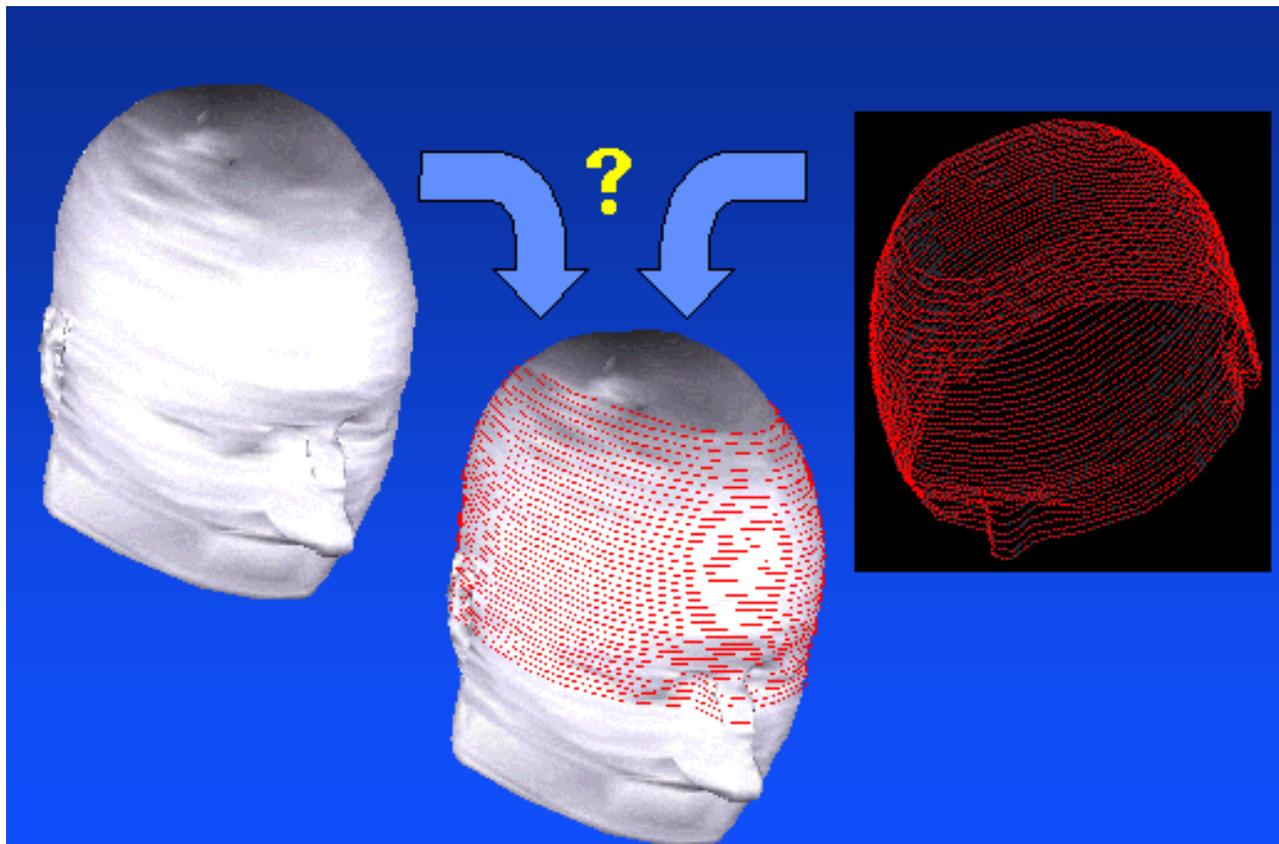
Example:

A transformation is searched to align the yellow, solid cube with the black wire-frame model .
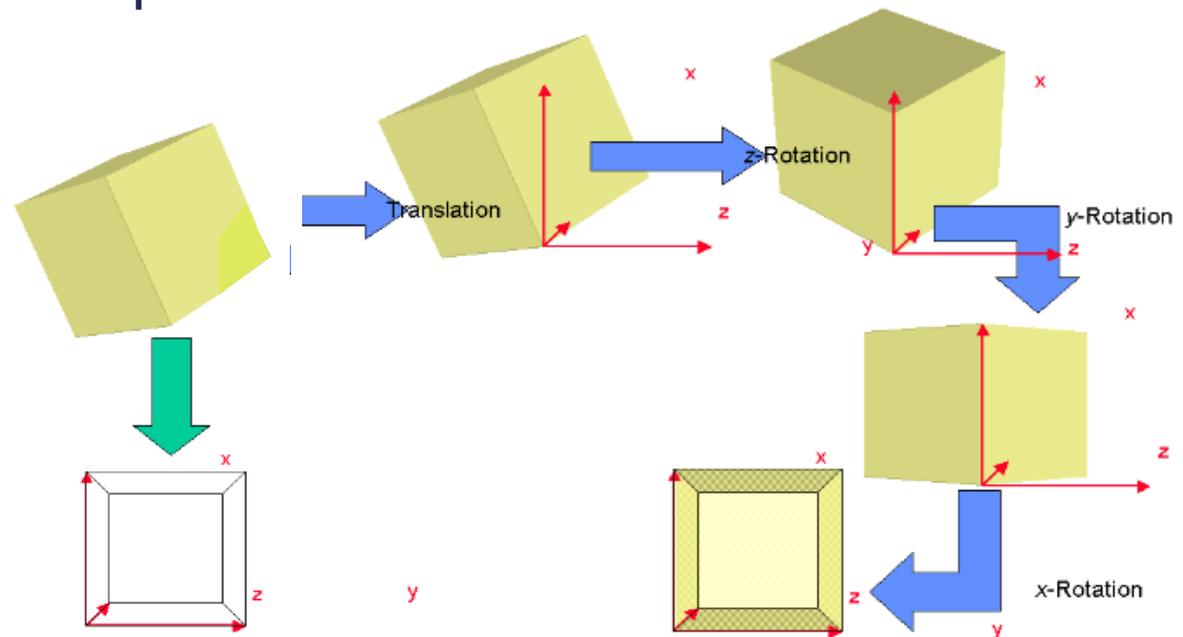
Image registration

Another example using multiple points at the surface as landmarks (surface matching):

Display of Registered Image Sequences
Image Fusion

Image registration can be considered as restricted to the calculation only of the transformations necessary, to superimpose information from one image onto the another.

However, we wish to see the result of registration:

The display of different data sets simultaneously can be summarized by the term "image fusion".

Display of Registered Image Sequences - Image Fusion

Example:

Image Fusion CT / MRI: left before, right after registration
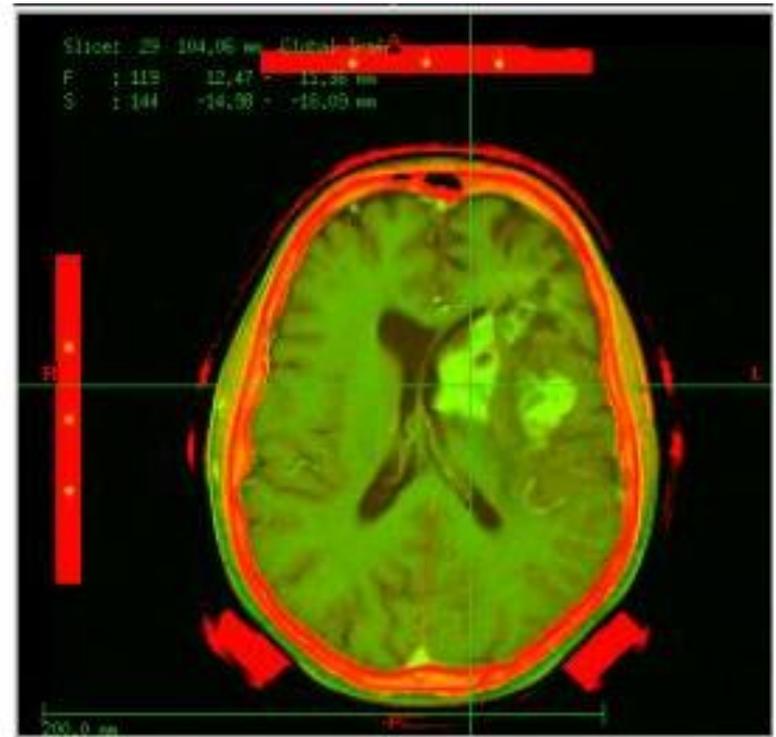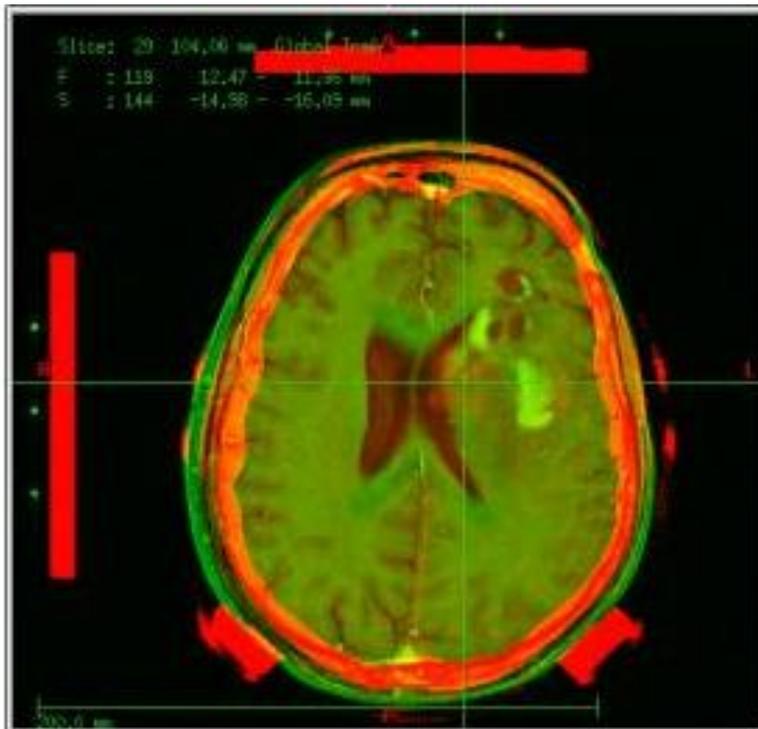
Patient treatment position and immobilization devices

Patients may require an external immobilization device for their treatment, depending upon:

- Patient treatment position,

or

- Precision required for beam delivery.

Example: Precision required in radiosurgery
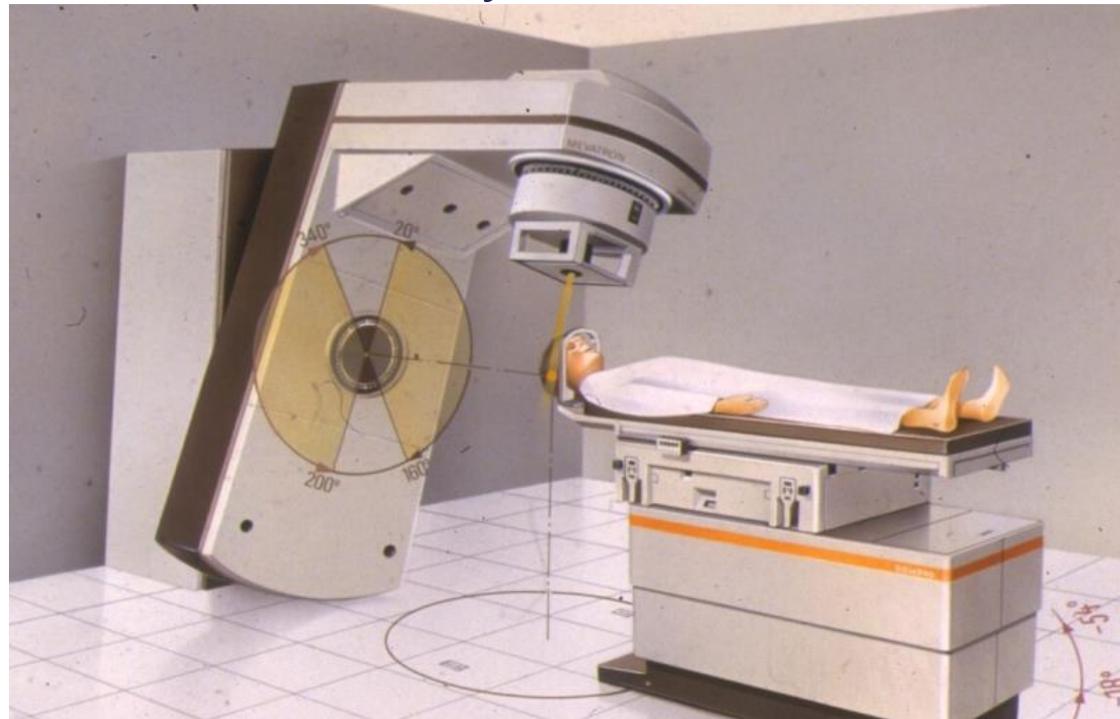
Immobilization devices have two fundamental roles:

1. To immobilize the patient during treatment.

2. To provide reliable means of reproducing the patient position from treatment planning and simulation to treatment, and from one treatment to another.

The immobilization means include masking tape, velcro belts, elastic bands, or even a sharp and rigid fixation system attached to the bone (stereotactic frame).

relocatable mask (scotch cast)
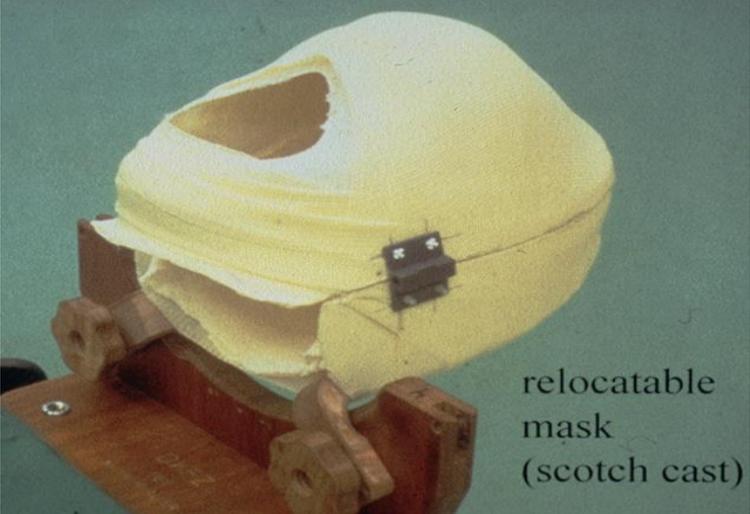
Yet another system uses a mask method adopted to the body.

The simplest immobilization device used in radiotherapy is the head rest, shaped to fit snugly under the patient's head and neck area, allowing the patient to lie comfortably on the treatment couch.

Several examples of headrests used for patient positioning and immobilization in external beam radiotherapy

Other types of immobilization accessories:

- Patients to be treated in the head and neck or brain areas are usually immobilized with a plastic mask which, when heated, can be moulded to the patient's contour.

- The mask is affixed directly onto the treatment couch or to a plastic plate that lies under the patient thereby preventing movement.

Special techniques, such as stereotactic radiosurgery, require such high precision in patient setup and treat-ment that conventional immobilization techniques are inadequate.

- In radiosurgery, a rigid stereotactic frame is attached to the patient's skull by means of screws

- The frame is used for target localization, patient setup, and patient immobilization during the entire treatment procedure.

Conventional Treatment Simulation Imaging

Patient simulation was initially developed to ensure that the beams used for treatment were correctly chosen and properly aimed at the intended target.
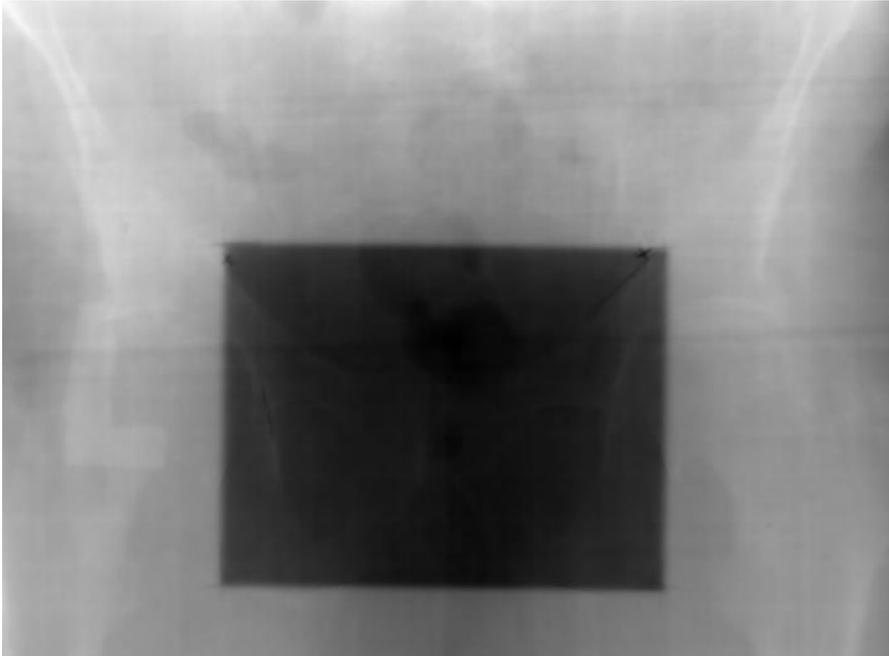
Example: The double exposure technique

The film is irradiated with the **treatment field** first.

Then the collimators are **opened to a wider setting** and a second exposure is given to the film.

Presently, treatment simulation has a more expanded role in the treatment of patients consisting of:

- Determination of patient treatment position.

- Identification of the target volumes and OARs.

- Determination and verification of treatment field geometry.

- Generation of simulation radiographs for each treatment beam for comparison with treatment port films.

Comparison of **simple simulation with portal image (MV)** with
conventional **simulation with diagnostic radiography (kV)** of the same anatomical site (prostate).
It clearly demonstrates the higher quality of information on anatomical structures with kV imaging.

Check portal film (MV)
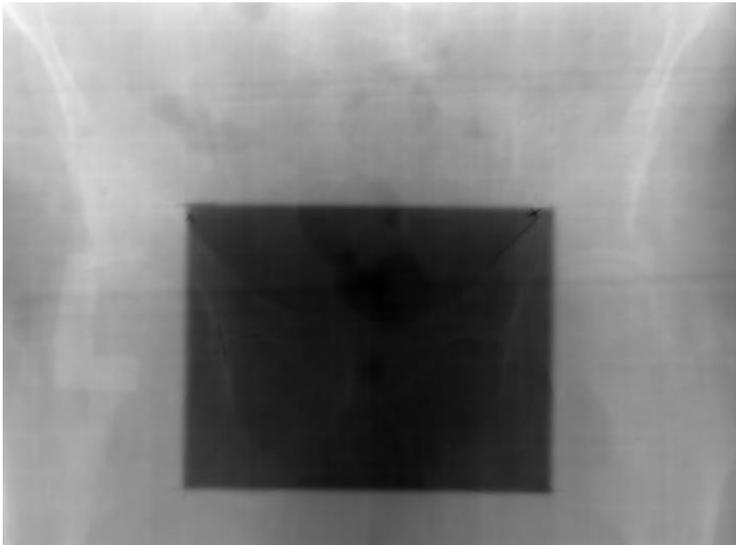
Reference simulator film (kV)
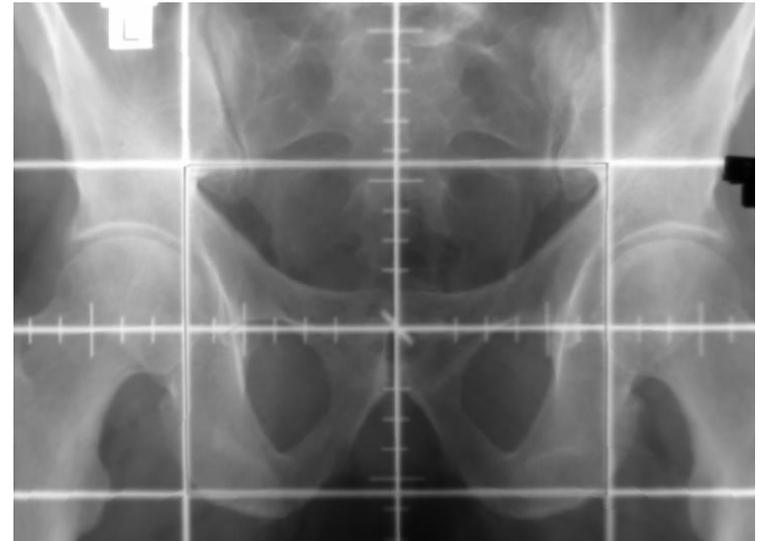
Modern simulators provide the ability to mimic many treatment geometries attainable on megavoltage treatment units, and to visualize the resulting treatment fields on radiographs or under fluoroscopic examination of the patient.

Adjustable bars made of tungsten can mimic the planned field size super-imposed on the anatomical structures.
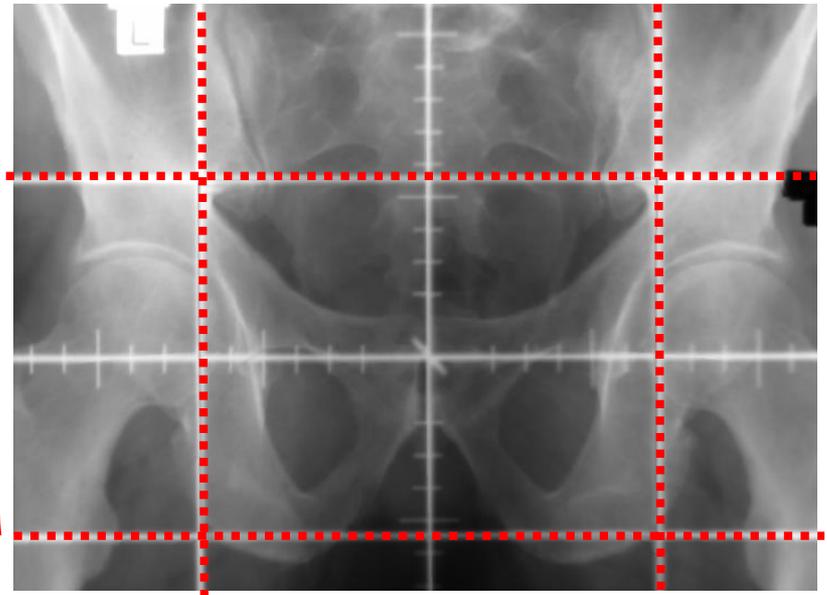
However, for the vast majority of sites, the disease is not visible on the simulator radiographs.

Therefore, shielding block positions can be determined only with respect to anatomical landmarks visible on the radiographs, such as:

- bony structures

- lead wire clinically placed on the surface of the patient

- surgically implanted fiducial markers

Determination of treatment beam geometry

- Once the final treatment geometry has been established, radiographs are taken:
    - as a matter of record,
    - which are also used to determine the shielding requirements for the treatment.

- Shielding can be drawn directly on the films, which may then be used as the blueprint for the construction of the blocks.
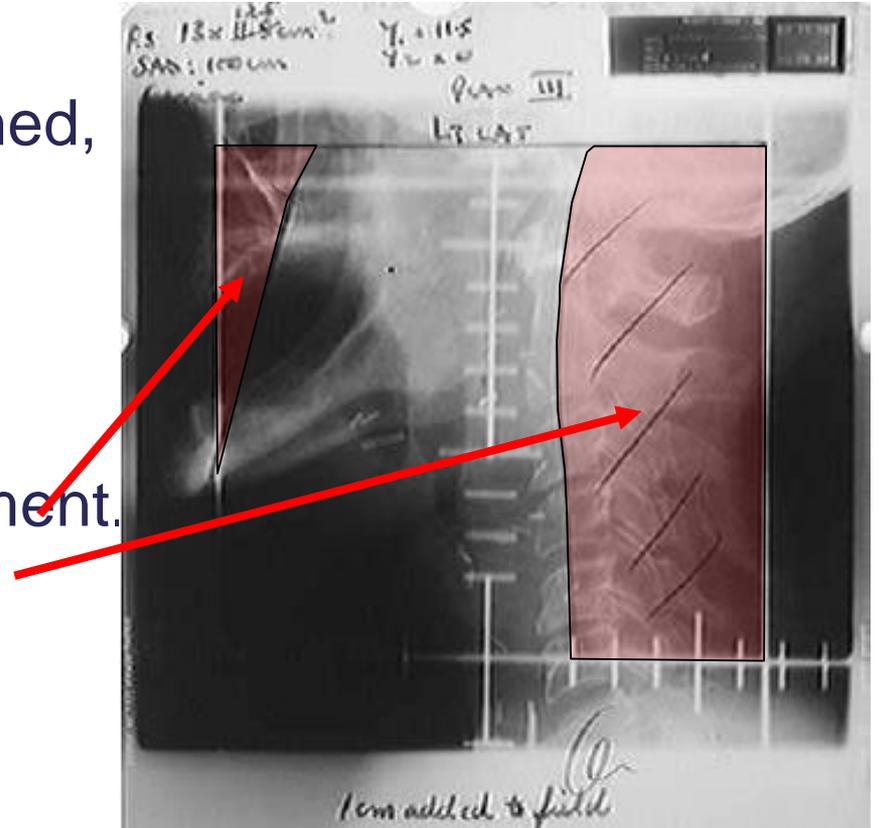
Computed tomography-based simulation

Modern simulation systems are based on computed tomography (CT) or magnetic resonance (MR) imagers and are referred to as CT-simulators or MR-simulators.

A dedicated radiotherapy CT simulator

The position of each slice and therefore the target can be related to bony anatomical landmarks through the use of scout or pilot images obtained at the time of scanning.

Computed tomography-based simulation: Virtual Simulation

- Virtual simulation is the treatment simulation of patients based **solely on CT information**.

- The premise of virtual simulation is that the CT data can be manipulated to render **synthetic** radiographs of the patient for arbitrary geometries.

- Such radiographs are also called:
        digitally reconstructed radiographs (DRR)

- DRRs are produced mathematically by tracing ray-lines from a virtual source position through the CT data of the patient to a **virtual film plane** and simulating the attenuation of x-rays.

- Advantage of DRRs is that

  - anatomical information may be used directly for the determination of treatment field parameters

  - The transfer error (patient positioned a second time at simulator) can be avoided.

Example of a DRR

Note:
- Gray levels,
- brightness,
- and contrast

can be **adjusted** to provide an optimal image.

Computed tomography-based simulation: Beam's eye view (BEV)

Beam's eye views (BEV) are **projections** through the patient onto a virtual film plane which is **perpendicular** to the beam direction.

Such BEVs are particularly useful in irregular beam shapes.

The projections may also include:

- Treatment beam axes

- Field limits

- Outlined structures

Examples for Beam's Eye View (BEV)

BEVs can be superimposed onto the corresponding DRRs resulting in a synthetic representation of a simulation radiograph.
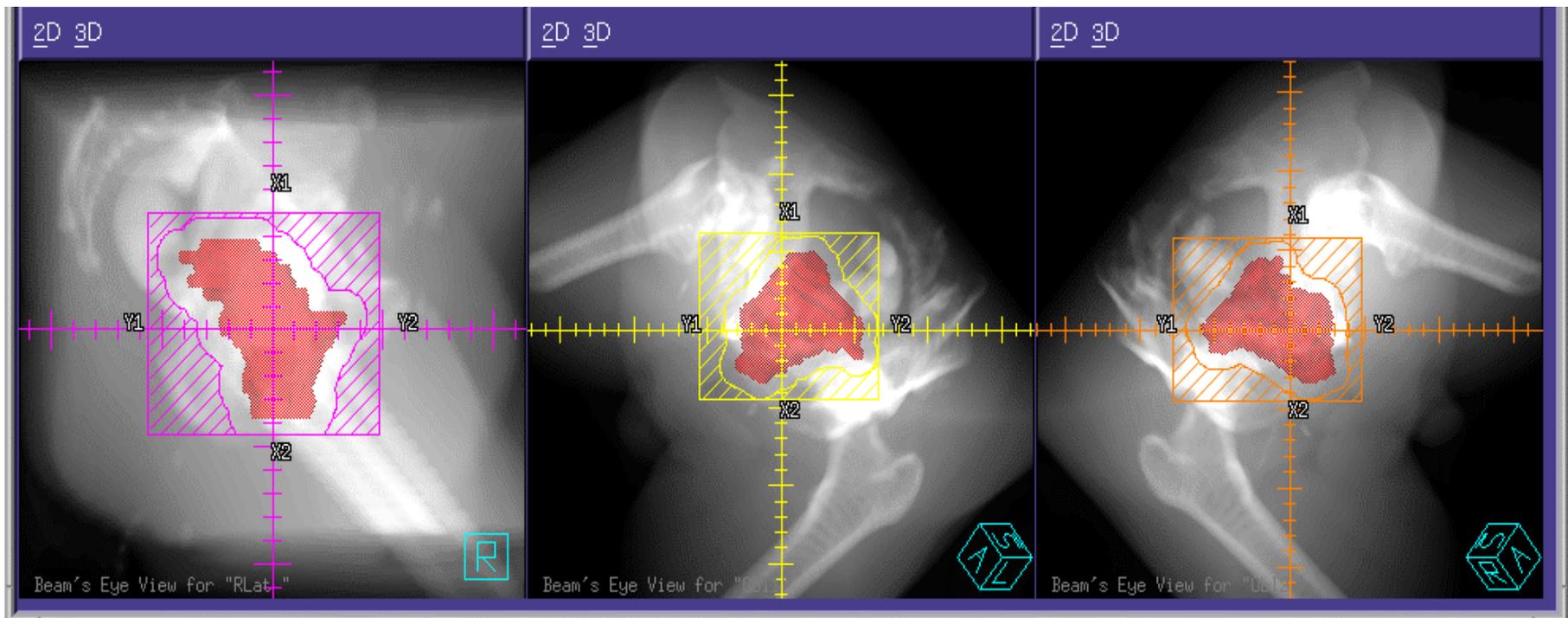
Conventional simulator vs. CT simulator

Conventional simulator

Advantages

❑ Useful to perform a fluoroscopic simulation in order to verify isocenter position and field limits as well as to mark the patient for treatment.

Conventional simulator vs. CT simulator

CT simulator

Advantages

- ❏ Increased soft tissue contrast.
- ❏ Axial anatomical information available.
- ❏ Delineation of target and OARs directly on CT slices.
- ❏ Allows DRRs.
- ❏ Allows BEVs.

Summary of simulation procedures

Goals and tools in conventional and CT simulation

Goals	Conventional	CT simulation
Treatment position:	Fluoroscopy	Pilot/scout views
Identification of target volume:	Bony landmarks	From CT data
Determination of beam geometry:	Fluoroscopy	BEV/DRR
Shielding design:	Bony landmarks	Conformal to target
Contour acquisition:	Manual	From CT data

Magnetic resonance imaging for treatment planning

MR imaging plays an increasingly more important role in treatment planning

Because …

The **soft tissue contrast** offered by magnetic resonance imaging (MRI) in some areas, such as the brain, is **superior to that of CT.**

Thus small lesions can be seen with greater ease.

Some Disadvantages of MR imaging:

MRI cannot be used for radiotherapy simulation and planning because:

- The **physical dimensions of the MRI** and its accessories may limit the use of immobilization devices and compromise treatment positions.

- **Bone signal is absent** and therefore digitally reconstructed radio-graphs cannot be generated for comparison to portal films.

- There is **no electron density information** available for heterogeneity corrections on the dose calculations.

- MRI is prone to **geometrical artifacts and distortions** that may affect the accuracy of the treatment.

To overcome these problems, many modern virtual simulation and treatment planning systems have the ability to **combine** the information from different imaging studies using the process of **image fusion** or **co-registration**.

CT-MR image co-registration or fusion combines the

- Accurate volume definition from MR

 with

- Electron density information available from CT.

Example
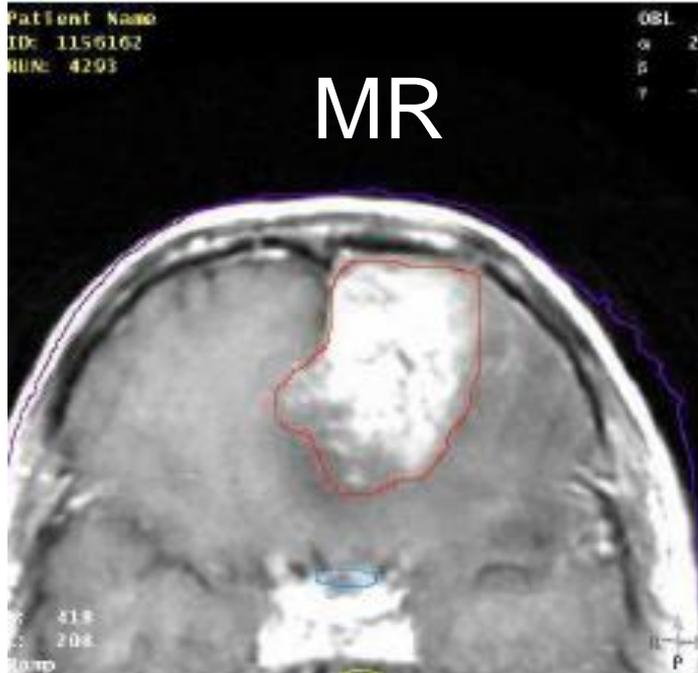
On the left is an MR image of a patient with a brain tumour. The target has been outlined …..

and the result was superimposed on the patient's CT scan.

Note that the particular target is clearly seen on the MR image but only portions of it are observed on the CT scan.

Summary: Imaging in radiotherapy patient data acquisition

1) **Patient dimensions** are always required for treatment time or monitor unit calculations, whether obtained with a caliper (very old-fashioned) or from CT slices. Dose calculation again is a apart only within the treatment planning system.

2) Almost any image modality can be used (and is used) for data acquisition for a patient undergoing radiotherapy

3) The process of distinguishing relevant structures or volumes from the background is called **segmentation**. Different methods have been developed for this.

4) The x y z coordinate system of images (series of images) of different image data must be correlated to each other. This is called **registration**, **matching** or **image correlation**.

Summary: Imaging in radiotherapy patient data acquisition

5) The display of different registered image data sets simultaneously is called "image fusion".

6) Immobilization devices have two fundamental roles:
    - To immobilize the patient during treatment.
    - To provide reliable means of reproducing the patient position from treatment planning and simulation to treatment.
      Many methods are available

7) Treatment simulation is a major component in patient data acquisition. It started with portal imaging, developed to dedicated X-ray simulators, CT-simulators, to (recently) cone beam imaging or MR imaging. It may be summarized by Image Guided RT.