Brachytherapy Planning and Quality Assurance

- Classical implant systems
- Most common clinical applications and modern dosimetry methods
- Quality assurance
Classical implant systems

- Manchester (Paterson-Parker)
- Quimby
- Paris
- With the advent of computerized treatment planning these are little used today with the possible exception of the Manchester System for cervix cancer treatments
The Manchester System

- Aims at producing as uniform a dose as possible within the treatment volume
- Sources of variable strength used
- Rules provided for placement of sources of different strengths
- Tables provided to determine treatment time
- Originally devised for Ra-226 but later extended to Cs-137
The Quimby System

- Developed by Edith Quimby at Memorial Hospital, New York
- Required uniform distribution of same strength sources
- Produced non-uniform dose distributions
- Tables provided to determine treatment times
- Originally devised for Ra-226 and Rn-222 seeds but later extended to Ir-192 and I-125
The Paris System

- Designed for Ir-192 wires but later extended to Ir-192 seeds in strands
- The sources should be equidistant arranged in patterns (squares or triangles)
- The dose (called the “basal dose”) is the arithmetic mean of the minimum dose rates located half-way between the sources in the well defined patterns
- Tables provided to determine treatment times
Most common clinical applications

- Gynecological treatments
- Prostate implants
- Breast implants
Gynecological brachytherapy

- Uterine cervix
- Vagina
- Endometrium
Cervix cancer: Manchester System
Fletcher-Suit tandem and ovoids

Tandem and ovoids are inserted into the uterine canal and vagina, respectively.
Some newer cervix cancer applicators
Manchester System: doses were calculated at two points, A and B.
Off-axis tandem

Meigooni, 2005
The American Brachytherapy Society recommended Point A doses with HDR for early disease.

<table>
<thead>
<tr>
<th>EBRT (Gy) @ 1.8 Gy/fraction</th>
<th>No. of HDR fractions</th>
<th>HDR dose/fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>6</td>
<td>7.5</td>
</tr>
<tr>
<td>20</td>
<td>7</td>
<td>6.5</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
<td>6.0</td>
</tr>
<tr>
<td>45</td>
<td>5</td>
<td>6.0</td>
</tr>
<tr>
<td>45</td>
<td>6</td>
<td>5.3</td>
</tr>
</tbody>
</table>

*Abbreviations: EBRT = external beam radiation therapy; HDR = high-dose-rate; LDR = low-dose-rate.*
The American Brachytherapy Society recommended Point A doses with HDR for advanced disease.

<table>
<thead>
<tr>
<th>EBRT (Gy) @ 1.8 Gy/fraction</th>
<th>No. of HDR fractions</th>
<th>HDR dose/fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>5</td>
<td>6.5</td>
</tr>
<tr>
<td>45</td>
<td>6</td>
<td>5.8</td>
</tr>
<tr>
<td>50.4</td>
<td>4</td>
<td>7.0</td>
</tr>
<tr>
<td>50.4</td>
<td>5</td>
<td>6.0</td>
</tr>
<tr>
<td>50.4</td>
<td>6</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Abbreviations: EBRT = external beam radiation therapy; HDR = high-dose-rate; LDR = low-dose-rate.
ICRU REPORT 89

Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix
Tissues imaged and planned in 3-D
ICRU 89 recommended prescribing, recording, and reporting levels

- **Level 1**: minimum requirements that should be followed by all centers, for all patients, and represents the minimum standard of treatment.

- **Level 2**: advanced standards of dose planning and treatment that allows a more comprehensive and standardized exchange of information between centers and based on a more complete set of parameters.
Example: Level 1 dose and delivery reporting for cervix brachytherapy

Dose reporting:
- TRAK
- Point A dose
- Recto-vaginal reference-point dose
- $D_{0.1cm^3}$ and $D_{2cm^3}$ for the bladder and rectum

Dose delivery pattern:
- Absorbed-dose rate/dose per fraction
- Number of fractions
- Time between fractions
- (Pulse number, size, time, if PDR)
- Overall treatment time
- Total EQD2 dose

Source and dose calculation:
- Radionuclide and source model
- Source strength
- Dose-calculation algorithm
Level 2: additional dose and delivery reporting

Dose reporting for defined volumes:
- $D_{98\%}, D_{90\%}, D_{50\%}$ for the CTV_{HR}
- $(D_{98\%}, D_{90\%})$ for the CTV_{IR} if used for prescription
- $D_{98\%}$ for GTV_{res}
- $D_{98\%}$ for pathological lymph nodes

Dose reporting OARs:
- Bladder reference point dose
- $D_{0.1cm^3}, D_{2cm^3}$ for sigmoid
- $D_{2cm^3}$ bowel
- Intermediate- and low-dose parameters in bladder, rectum, sigmoid, bowel
  (e.g., $V_{15\text{ Gy}}, V_{25\text{ Gy}}, V_{35\text{ Gy}}, V_{45\text{ Gy}}$ or $D_{98\%}, D_{50\%}, D_{2\%}$)
- Vaginal point doses at level of sources (lateral at 5 mm)
- Lower- and mid-vagina doses (PIBS, PIBS $\pm\ 2\text{ cm}$)

\[ ^a \text{Surrogate points for volumetric vaginal dose assessment.} \]
Vaginal brachytherapy

- Can be treated low dose rate although, nowadays, most commonly, high dose rate
- Usually use cylindrical applicator of appropriate diameter
- Stepping pattern designed to give uniform dose around the applicator at selected depth in tissue, typically 0.5 cm
Intracavitary applicators used for vaginal brachytherapy

Use the largest diameter applicator that is comfortable for the patient so as to produce the best depth dose
Endometrial brachytherapy

- Can be treated low dose rate although, nowadays, most commonly, high dose rate
- For post-hysterectomy patients
  - treat the vagina (vaginal cuff brachytherapy)
- For other patients
  - treat the vagina plus the uterine cavity with special applicator
Endometrial brachytherapy
Typical dose distribution

Fig. 4
Examples of isodose distribution of an optimized treatment plan for treating inoperable primary endometrial cancer with a Y-shaped applicator.
ABS HDR dose guidelines
(if no added external beam)

<table>
<thead>
<tr>
<th>No. of HDR fractions</th>
<th>HDR dose/px</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8.5 Gy at 2 cm</td>
</tr>
<tr>
<td>5</td>
<td>7.3 Gy at 2 cm</td>
</tr>
<tr>
<td>6</td>
<td>6.4 Gy at 2 cm</td>
</tr>
<tr>
<td>7</td>
<td>5.7 Gy at 2 cm</td>
</tr>
</tbody>
</table>

HDR doses are specified at 2 cm from the midpoint of intrauterine sources
Prostate brachytherapy

- There are two major alternatives:
  - Permanent implants with either I-125 or Pd-103 seeds
  - Temporary high dose rate implants with Ir-192 or electronic brachytherapy
Ultrasound-Guided Transperineal Prostate Brachytherapy
Series of transrectal ultrasound (TRUS) images
TRUS images used for planning
Schematic of the planning and treatment process for permanent implants

Moorrees et al. Radiation Oncology 2012, 7:196
Sources used for permanent prostate implants

- With I-125 (half life 60 days) the dose is delivered over many months
- With Pd-103 (half life 17 days) the dose is delivered over many weeks
- The total dose delivered to infinity is calculated by the formula:
  \[ \text{Total dose} = (\text{initial dose rate}) \times (\text{mean life}) \]
Examples

1. If the initial dose rate for an I-125 implant is 7 cGy/h, then the total dose to complete decay is:
   
   \[ 7 \times 1.44 \times 60 \times 24 = 14,515 \text{ cGy} \]
   
   i.e. about 145 Gy

2. If the initial dose rate for a Pd-103 implant is 21 cGy/h, then the total dose to complete decay is:
   
   \[ 21 \times 1.44 \times 17 \times 24 = 12,338 \text{ cGy} \]
   
   i.e. about 123 Gy
American Brachytherapy Society recommended total doses for prostate treatments

<table>
<thead>
<tr>
<th>Prescription doses to the planning target volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{125}\text{I})</td>
</tr>
<tr>
<td>Monotherapy</td>
</tr>
<tr>
<td>Combination</td>
</tr>
<tr>
<td>EBRT</td>
</tr>
<tr>
<td>PPB dose</td>
</tr>
<tr>
<td>(^{103}\text{Pd})</td>
</tr>
<tr>
<td>Monotherapy</td>
</tr>
<tr>
<td>Combination</td>
</tr>
<tr>
<td>EBRT</td>
</tr>
<tr>
<td>PPB dose</td>
</tr>
</tbody>
</table>

PPB = permanent prostate brachytherapy; EBRT = external beam radiation therapy.

\(^{a}\) 2 Gy/d also acceptable.
ABS Prostate TG suggested doses for HDR prostate treatments

For monotherapy either

10.5 Gy x 3 fractions

or 8.5-9.5 Gy x 4 fractions

or 6.0-7.5 Gy x 6 fractions
ABS Prostate TG suggested doses for HDR prostate treatments

As a boost in combination with 36-40 Gy EBRT

15 Gy x 1 fraction

or, with 40-50 Gy EBRT either

9.5-10.5 Gy x 2 fractions

or 5.5-7.5 Gy x 3 fractions

or 4.0-6.0 Gy x 4 fractions
Brachytherapy for breast cancer can be used after lumpectomy either as a boost to external beam therapy or as monotherapy.

Two major techniques are applied:
1. needles are inserted interstitially into the breast using a template with either LDR or HDR, or
2. an applicator is inserted at the time of surgery into the cavity and expanded so as to make the cavity roughly spherical and an HDR is source is stepped through the applicator.
Template for interstitial needle technique
Interstitial needle technique
APBI applicators available

- MammoSite: Hologic
- Contura: SenoRX
- Savi: Cianna Medical
- ClearPath: North America Scientific
- Double Balloon: Best
- Axxent Balloon: iCAD (electronic brachytherapy)
Example: the MammoSite

There are two types: a single lumen (shown) and multiple lumens

Njeh et al. Radiation Oncology 2010 5:90
Typical APBI brachytherapy doses when used as monotherapy

- **LDR**: 45-50 Gy at about 0.5 Gy/h
- **HDR**: 34 Gy at 1.0 cm outside the cavity wall in 10 fractions
# Imaging for brachytherapy

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IMAGE ASSISTED PROVISIONAL TREATMENT PLANNING</strong></td>
<td>treatment simulation and provisional dose calculation&lt;br&gt;conventional radiography, sectional imaging: MR, CT, US, PET</td>
</tr>
<tr>
<td><strong>IMAGE GUIDED APPLICATION</strong></td>
<td>Radiography, MR, CT, US, endoscopy&lt;br&gt;with or without on-line treatment planning</td>
</tr>
<tr>
<td><strong>IMAGE ASSISTED DEFINITIVE TREATMENT PLANNING</strong></td>
<td>Imaging after application for definitive treatment planning&lt;br&gt;(Radiography, US, CT, MR)</td>
</tr>
<tr>
<td><strong>IMAGE ASSISTED QUALITY CONTROL OF DOSE DELIVERY</strong></td>
<td>Imaging for quality control during or after brachytherapy&lt;br&gt;Radiography, CT, MR</td>
</tr>
</tbody>
</table>

Gerbaulet et al, 2002
General flow scheme for a brachytherapy procedure: preparation and application

Preparation
- patient
- medical and technical documents
- pre-planning
  (decision about application technique, applicator geometry, dose constraints)

Anaesthesia
(if applicable)

QA for equipment
- daily checks
- visual inspection of applicators
- availability of dosimeters and emergency equipment

Application
(with or without image guidance using X-ray, US, CT or MR)
Flow scheme for brachytherapy imaging for treatment planning

Localisation imaging
- X-ray images
  - drawing of reference points
    - (e.g. ICRU points, reconstruction of geometry with TPS)

Sectional imaging
- MR or CT if applicable
  - transfer of images to TPS

Delineation of target volume and organs at risk
  - (optional fusion of different imaging techniques, e.g. matching between X-ray reconstruction and CT/MR)
General flow scheme for a brachytherapy procedure: planning and treatment

- **Treatment planning**
  (based on dose prescription, reference points, dimensions of isodose and/or DVH constraints)

- **Validation of plan**
  joint decision between team members
  double check of essential parameters

- **Radiation treatment**
  connection between applicators and afterloader
  in-vivo dosimetry
  nursing care of patient

- **Documentation**
  print-out of treatment data
  signatures
  archive of patient file
Quality assurance program is needed to assure:

- safety of the patient, the public, and the staff
- positional accuracy
- temporal accuracy
- dose delivery accuracy
ESTRO Brachytherapy QA Guidelines

Edited by
Jack Venselaar
José Pérez-Calatayud

Supported by the EU
“Europe against Cancer” Programme
Grant Agreements N°SPC.2002480 / S12.322029

A PRACTICAL GUIDE TO QUALITY CONTROL
OF BRACHYTHERAPY EQUIPMENT

EUROPEAN GUIDELINES FOR QUALITY ASSURANCE IN RADIOTHERAPY
Booklet No. 8
AAPM Report No. 59: Code of practice for brachytherapy physics

RECOMMENDED QUALITY ASSURANCE PROGRAM FOR BRACHYTHERAPY EQUIPMENT

A. Manual afterloading brachytherapy
B. Remote afterloading brachytherapy devices
   1. Daily remote afterloader QA protocol
   2. Quarterly remote afterloader QA protocol
   3. Acceptance testing and annual remote afterloader QA
C. Quality assurance for treatment planning and evaluation systems
Safety of the patient, the public, and the staff

- **Error avoidance**
  - clear prescriptions, equipment testing, patient identification, etc.

- **Emergency procedures**
  - training staff, availability of equipment, etc.

- **Radiation safety**
  - room shielding, control of sources, monitoring devices, interlocks, etc.
Positional accuracy

- Machine programming parameters
  - *accurate transfer of positional data from treatment planning system to treatment machine*
  - *correct lengths, positions, channel numbers*
- Correct location of applicators, catheters, etc.
  - *for each patient treatment*
- Correct location of sources
  - *for each patient treatment*
Typical source positioning accuracy QA phantom

FOR MONTHLY / DAILY CONSTANCY CHECKS OF HDR SOURCE POSITIONING AND STEPPING ACCURACY UTILIZING GAFCHROMIC® RTQA FILM.
Temporal accuracy

- **LDR**
  - need to assure that treatment is terminated once the prescribed dose is delivered
- **Remote afterloading (LDR, PDR and HDR)**
  - timer and dwell time accuracy
  - magnitude of transit dose
  - accurate transfer of temporal data from treatment planning system to treatment machine
Dose delivery accuracy

- Physical aspects
  - source strength calibration, accurate data in treatment planning computer, accurate decay correction, account for effect of applicator attenuation, etc.

- Clinical aspects
  - accuracy of anatomical data and transfer of that data to the treatment planning system
  - accuracy of planning system, optimization, etc.
Source strength calibration

- Primary standards laboratories have developed advanced methods to calibrate different sources.
- These are typically well beyond the scope of most users who need to check source strengths in-house.
Source strength verification by the user

This is typically done using a well-type ionization chamber that has been calibrated by the primary standards laboratory or at a secondary standards lab using a method traceable to that at the primary lab.
Typical well-type ionization chambers

- Standard Imaging
- Nucletron
- PTW
Data supplied by the calibration lab

- Sweet spot location
- Air kerma strength calibration factor for the chamber
- Source used for the calibration
- Irradiation conditions
- Traceability to national calibration lab
The location of the sweet spot on the central axis of the chamber is determined by moving a single source and taking multiple readings.
Pre-treatment brachytherapy QA for each patient

- Check for completeness of printed information
- Check for consistency of plan with treatment prescription
- Double check of data by independent second person
- If possible perform (simple) manual calculation of treatment time
- Signing of document before treatment starts by physician and physicist
Summary

- Classical systems little used today except for the Manchester System for cervix cancer
- Computerized planning now used with advanced imaging
- QA program for delivery and planning equipment, input and output data, essential to assure safety and accuracy