LDR Intracavitary Brachytherapy
Applicators

UT MD Anderson Cancer Center
Intracavitary Brachytherapy

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Collaborators

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Conflict of Interest

- Nucletron sponsored research agreement supports a portion of this research
- Transpire sponsored research agreement and SBIR supports a portion of this research
Course Objectives

- Discussion
  - The most commonly used LDR intracavitary brachytherapy (ICB) applicators
  - Need for ICB applicators that permit CT & MR imaging of ICB implant
  - Importance of including applicators’ attenuation effects on the 3D dose calculations for ICB implants
  - The UTMDACC system for ICB implants
Fletcher Family of Applicators
Manual Afterloaded

- Medium caps
- Large caps
- Small ovoids
- Tandems
- Flanges
- Tandem source carrier
- Ovoid source carriers
- Vaginal cylinders
- Seed inserter

Mini ovoids
Fletcher Tandem and Ovoids

• Based on Manchester System
• Stainless steel
  – Manchester system rubber
• Cylindrical ovoid
  – Manchester ovoid, prolate spheroid, conformed to isodose surface of $^{226}$Ra tube source
• Bladder and rectal shields
• Preloaded
Shields in FSD System

Source should be centered along axis of ovoid
Bladder and rectal shields on medial aspect of ovoid

Delclos, et al., Cancer 41, 970-979, 1978
Fletcher Preloaded Ovoids

Delclos, et al., Cancer 41, 970-979, 1978
Suit Afterloading

• Modified Fletcher applicators for afterloading
  - Based on Henschke afterloading idea
• Ovoid afterloading required
  - Suspending ovoid source carriers on double hinge device
  - Slight change to shield design
  - Increased length of ovoid 1 mm
Delclos Afterloading

• Improved design of ovoid source carrier
• Shields returned to original position of Fletcher design
• Ovoid same length as original Fletcher design
• Mini-ovoids
• Promoted dome and cylinder applicators
Evolution of FSD Ovoids

Delclos, et al., Cancer 41, 970-979, 1978
Evolution of FSD Ovoids

Delclos, et al., Cancer 41, 970-979, 1978
Dome

- Walstam capsule
  - $^{137}\text{Cs}$
  - 8mm PL
  - AL depends on activity
    - 2.1mm or 4.2mm
Dome and Cylinders

Walstam capsule in dome

Tube source in cylinders

Spacers used to achieve desired dose distribution
Selectron LDR

Fletcher-Suit-Delclos Ovoids

- small ovoids - one ovoid with medium cap
- mini ovoids
- 15 degree mini ovoid
- 30 degree "short" small ovoid
- medium cap
- large cap
- "short" large cap
- 15 degree small ovoid
- 30 degree small ovoid
- ovoid - 33 mm long "short" ovoid - 28 mm long
- 15 degree small ovoid
Selectron LDR
Fletcher-Suit-Delclos Tandems

Flange and flange with keel

#1 Tandem
#2 Tandem
#3 Tandem
#4 Tandem
Henschke Applicator

- Similar to Fletcher system
- Ovoid source length along direction of handle facilitates afterloading
- Afterloading idea adapted by Suit for Fletcher system

from Nucletron catalogue
Mold (Moulage) Applicators

• Mold applicators typical in France
  – Créteil
  – Institut Gustave Roussy
  – Saint – Cloud

• Use $^{192}$Ir or $^{137}$Cs, depending on institution

• Different techniques and dosimetry depending on institution

• Will review Créteil technique as example
  – $^{192}$Ir wire, all wire same linear intensity
Créteil Mold Applicators

- Alginate impression of vagina
- Acrylic mold
- Custom (right) or prefabricated
  - (2.5, 3.5 or 4.5 cm)
- Plastic guide tubes
  - 2 vaginal sources
  - 1 uterine source
  - Lead shot 6 & 12 o’clock
- Tandem & ring – similar geometry

Créteil Mold Applicators
Vaginal Sources

- R & L Plastic guide tubes, 7mm OD
- Centered 7mm from external lateral surfaces of mold
- $^{192}\text{Ir}$ wire 0.5mm diameter, placed in plastic tube 1.6mm OD, centered in plastic guide tubes

Créteil Mold Applicators

Vaginal Sources

- Each source length
  0.8 times the
distance between
sources

- Separation between
  ends of sources
equal on bladder
and rectal sides

From *A Practical Manual of Brachytherapy*, Pierquin & Marinello,
Créteil Mold Applicators

Uterine Source

- Semi-rigid plastic guide tube, 7mm OD, 35 mm long, distal end sealed
- Centered in mold
- $^{192}$Ir wire 0.5mm diameter, placed in plastic tube 1.6mm OD, centered in plastic guide tube

Créteil Mold Applicators
Uterine Source

- Distal end of $^{192}\text{Ir}$ extends to 5mm below top of uterus
- Proximal end of $^{192}\text{Ir}$ extends below plane of vaginal sources, 5mm if cervix diameter less than 4cm or 15mm if larger diameter

Créteil Mold Applicators
Dosimetry

- Dosimetry – day after implant
- Well defined geometry
- Uniform and equal linear activity for vaginal and uterine sources
- Same time duration for vaginal and uterine sources

Créteil Mold Applicators
Dosimetry

- Adherence to rules - pear shaped reference isodose (RD) surface proportional to cervix size
- \( \text{RD} = 0.46 \, \text{Gy/day per} \) 1\( \mu \text{Gy}\)-m\(^2\)/hr-cm linear activity
- Example - prescribe 30Gy in 2 days, requires linear activity of 32.6\( \mu \text{Gy}\)-m\(^2\)/hr-cm w/o decay for \(^{192}\text{Ir}\)

Créteil Mold Applicators
Dosimetry

• Reference isodose (RD) surface - 7mm from surface of mold at level of vaginal sources, 7mm from distal end uterine source
• Cervical dose (at lead shot) approx. twice RD
• Rectal dose less than or equal to RD

CT/MR Compatible Applicators

- Weeks applicators
- Adaptable applicator
Weeks Applicator
"Model 1"

- CT compatible
- Shielded ovoids
- Shields afterloaded through acrylic handles
- Difficult for MD to see to position ovoids with large handles to allow afterloading shields

Weeks Applicator
“Model 2”

FSD shields

Weeks shields

Ovoid source carriers designed to provide shielding equal to FSD ovoids, external dimensions same as FSD.

Adaptable Applicator

• Shield repositioned after placement in patient to
  - Reduce CT artifacts
  - Optimize shielding effects on critical structure
  - Feedback to verify correct positioning

*Patent pending*
MCNPX2.5.c  Attila
1.8 GHz Opteron CPU
18 hr 16 min  2 hr 29 min

Attila

• Deterministic transport solver including charged particles – discrete ordinates method

• Compatible with CAD programs, e.g., Solid Works, for input of geometry files

Transpire, Inc.  www.radiative.com
Attila

- Solid Works model of tandem and ovoids for clinical implant
Historical Perspective

UTMDACC I CBT

• UTMDACC database
  - dates to 1960
  - 7000 radiation therapy patients
    • 40 – 45 Gy external beam (typical)
    • 2 LDR ICB 48 hour treatments (typical)

• Textbook of Radiotherapy, Fletcher
  - Rules formalized

• Radium treatments
  - Tube sources, 22mm PL, 15 mm AL
  - 1 mm Pt filtration
Central recurrence:

- IB1: 1–2%
- IB2-II: 10–15%
- III: 25–30%

Death from disease

- IB1: 10 - 15%
- IB2-II: 30 – 40%
- III: 50 – 60%

Disease Specific Survival

Eifel
Overall Major Complications (G=3 or higher) 3489 patients

At 10 Years

- Rectum 3.3%
- Sigmoid 0.2%
- Small Bowel 4.2%
- Bladder 3.0%

Eifel
Current Treatments

- ICB boost delivered with $^{137}\text{Cs}$
  - Selectron $^{137}\text{Cs}$ LDR remote afterloaders
  - Manually afterloaded $^{137}\text{Cs}$
    - 20 mm PL, 13.5 mm AL
  - Typically prescribed by geometry in mgRaeq hours ($1 \text{ mgRaeq} = 7.227 \text{U}$)
  - “sources” or “inches” or “custom”
The M. D. Anderson System for Intracavitary Implants

- First described by Fletcher in the Textbook of Radiotherapy, 1969
- Not based upon Point A dose or dose rate
The conditions first described by Fletcher

- Tandem activity 4 to 6 mgRaeq/cm
  • Use spacers to achieve this linear intensity, if required
- Adequate dose to paracervical areas
- Respect mucosal tolerance
# Fletcher System

Table 11-8. Summary of Combination of External and Intracavitary Irradiation in Carcinoma of the Cervix with Intact Uterus

<table>
<thead>
<tr>
<th>Tumor size</th>
<th>Whole pelvis</th>
<th>Radium</th>
<th>Parametrial</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤1 cm (Fig. 11-10)</td>
<td>None</td>
<td>72-2 wk-48</td>
<td>10,000</td>
<td>None</td>
</tr>
<tr>
<td>1–3 cm lesions of exocervix</td>
<td>2000 rads</td>
<td>48-2 wk-72</td>
<td>≤7500</td>
<td>If anatomy is not good, radium is reduced and additional treatment is given with external irradiation.</td>
</tr>
<tr>
<td>with little or no extension</td>
<td>4000 rads</td>
<td>48-2 wk-48</td>
<td>≤5500</td>
<td>The amount of whole pelvis and parametral irradiation depends upon (1) extent of disease, (2) patient anatomy, and (3) geometry and location in pelvis of radium system.</td>
</tr>
<tr>
<td>to parametra or fornices</td>
<td>4000 rads</td>
<td>48-2 wk-48</td>
<td>5500-6500‡</td>
<td>If regression is poor and there is no parametrical involvement, one single radium insertion (72 hr or 5000 mg-hr—whichever comes first) followed by an extrafascial hysterectomy.</td>
</tr>
<tr>
<td>(Fig. 11-11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulky central disease &gt;6 cm</td>
<td>4000 rads</td>
<td>72</td>
<td>5000</td>
<td>Extrafascial hysterectomy performed 6 wk after irradiation.</td>
</tr>
<tr>
<td>“barrel-shaped” endocervical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tumor (Fig. 11-12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulky central disease &gt;6 cm</td>
<td>4000 rads</td>
<td>48-2 wk-48</td>
<td>5500-6600‡</td>
<td>May add 1000 rads to side of major involvement.</td>
</tr>
<tr>
<td>extending near or to pelvis</td>
<td>5000 rads</td>
<td>48-2 wk-24</td>
<td>4000-5000‡</td>
<td></td>
</tr>
<tr>
<td>wall(s) and/or lower vagina</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fig. 11-14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Massive disease or bladder</td>
<td>6000 rads</td>
<td>72</td>
<td>3000-4000‡</td>
<td></td>
</tr>
<tr>
<td>or rectal involvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fig. 11-15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Use whichever maximum comes first, either the time or mg-hr.
† May use longer time first if vault size may not permit colpostats at second application.
‡ The larger figures for radium are used if lesions have not clinically disappeared at time of second radium: the lesser figures are used if there has been excellent regression of disease.
§ Reduce parametral irradiation by 500 rads for patients with previous pelvic surgery or pelvic inflammatory disease.
Optimized System Geometry

- Optimal placement of the applicators in the uterus and vagina.
- Optimal placement of the radioactive sources in applicators
- Pear-shaped dose distribution - high dose to the cervical and paracervical tissues; reduced dose to the bladder and rectum
Lateral View of Optimized Applicator Placement

- Tandem - 1/3 of the way between S1 - S2 and the symphysis pubis
- The tandem - midway between the bladder and S1 - S2
- Marker seeds should be placed in the cervix
- Ovoids should be against the cervix (marker seeds)
- Tandem should bisect the ovoids
- The bladder and rectum should be packed away from the implant
AP View of Optimized Applicator Placement

- The ovoids should fill the vaginal fornices, add caps to increase the size of the ovoids if necessary.
- The ovoids should be separated by 0.5 – 1.0 cm, admitting the flange on the tandem.
- The axis of the tandem should be central between the ovoids.
Optimized System Placement
In Practice

• Katz and Eifel evaluated 808 insertions of tandem and ovoids at MDACC
• Median distance between the sacrum and the tandem, 4.0 cm
• Interquartile (IQ) range, 2.2 – 4.9 cm.
• Median distance between tandem and pubis, 8.4 cm
• IQ range, 7.6 - 9.1 cm.
Tandem Loading

- 4 to 6 mgRaeq/cm
- Physical length (PL) of inferior source does not extend beyond flange, typically
- If ovoids are displaced inferior to cervix based on marker seeds, inferior end of PL of inferior source 2mm to 3 mm above superior aspect of ovoids
- Source activity in tip, typically higher than other sources, increases lateral coverage
- 30 to 45 mgRaeq over 6 to 8 cm
Ovoid Loading

- Small ovoids, 2 cm, 10 – 15 mgRaeq
- Medium ovoids, 2.5 cm, 15 – 20 mgRaeq
- Large ovoids, 3 cm, 20 mgRaeq
- Mini-ovoids, 1.6 cm, 5 mgRaeq, rarely 7.5 or 10 mgRaeq
- Selectron ovoids – 33 mm long, “short small” – 28 mm long
Treatment Planning

• Planes
  – Lateral throw off
  – Fletcher trapezoid
  – Pelvic brim
  – Sagittal

• Critical Structure Doses
  – Bladder
  – Rectum
  – Vaginal Mucosa, vault dose, 3 & 9 o’clock
Lateral Throw Off Plane

- Lateral throw off (LTO) plane passes through the internal os (IO) and the center of the activity in the ovoids (MO)
Dose Evaluation
Lateral Throw Off Plane

- 3150 cGy isodose line of interest
- 3150 cGy line from Manchester system typical prescription 7000 R
- 7000 R becomes 6300 cGy Shalek & Stovall conversion
- Typically two 48 hour insertions
- 3150 cGy per insertion
Dose Evaluation
AP View

• Pear-shaped 3150 cGy volume should show
  - high dose to the cervix and paracervical tissues
  - reduced dose to the bladder and rectum
  - no high or low dose volumes
Mucosal Tolerances

• Respect normal tissue tolerances, total external beam dose plus brachytherapy dose
  - Bladder - limit 75 to 80 Gy
  - Rectum - limit 70 to 75 Gy
  - Vaginal surface dose - limit 120 to 140 Gy

• Integral dose to the pelvis
  - 6000 to 6500 mgRaeq-hrs
Mucosal Tolerances

• Vaginal surface doses
  - Vault dose, dose to ovoid surface (vaginal mucosa) from source in that ovoid
  - 3 o’clock and 9 o’clock doses
    • Dose to ovoid surface includes vault dose plus doses from tandem sources and other ovoid source, approximate calculation
    • 3 o’clock dose at lateral surface of left ovoid
    • 9 o’clock dose at lateral surface of right ovoid
Lateral Throw Off Plane

- Tandem and Ovoid loadings and hours
- mgRaeq-hour
- TRAK
- 3150 cGy line
- Doses to
  - Pelvic points A and B
  - 3 o’clock; 9 o’clock
  - Bladder
  - Rectum
  - Vault
Dose to Point A

- External beam dose of 40 to 45 Gy plus brachytherapy dose from two 48 hour insertions to point A total
  - 80 to 85 Gy for small IIA and IIB tumors
  - 85 to 90 Gy for larger tumors
3D CT Treatment Planning
3D Treatment Planning
3D Treatment Planning

- Better knowledge of minimum tumor dose
- Better knowledge of normal tissue doses
- Improve investigation of dose responses
- Potential to improve applicator positioning
3D Treatment Planning

- 93 implants, ICRU bladder and rectal points compared 3D CT plans
- ICRU bladder point significantly lower ($p<0.001$) than 3D CT plan point $D_{BV2}$

$D_{BV2} = 2\text{cm}^2$ volume receiving highest dose

3D Treatment Planning

- ICRU rectal point, surrogate for $D_{RV2}$, ($p=.561$)

3D Treatment Planning

Subset of 12 patients, Pelloski data. MCNPX2.5.c study accounted for shielding effects.

Dose difference curves comparing shields to no shields.

3D Treatment Planning

- **Bladder**
  - Mean dose reduction 53cGy to 5% of surface area
  - Max dose reduction 150cGy to 5% of surface area

- **Rectum**
  - Mean dose reduction 195cGy to 5% of surface area
  - Max dose reduction 405cGy to 5% of surface area

Dose Specification in ICB

“...universal agreement does not exist as to the superiority of any one system. The problem is perhaps with the nature of brachytherapy, no more sophisticated than gourmet cooking...as in cooking, there is a little bit of everything: art, science, technique, and taste.”

Dose Specification in ICB

“It is realized that the weakness of the whole system lies in the inability to visualize the target volume. Unless the target volume can be accurately determined and superimposed on the isodose pattern, one cannot determine the minimum target dose.”

Art, Science, Technique, and Taste
end