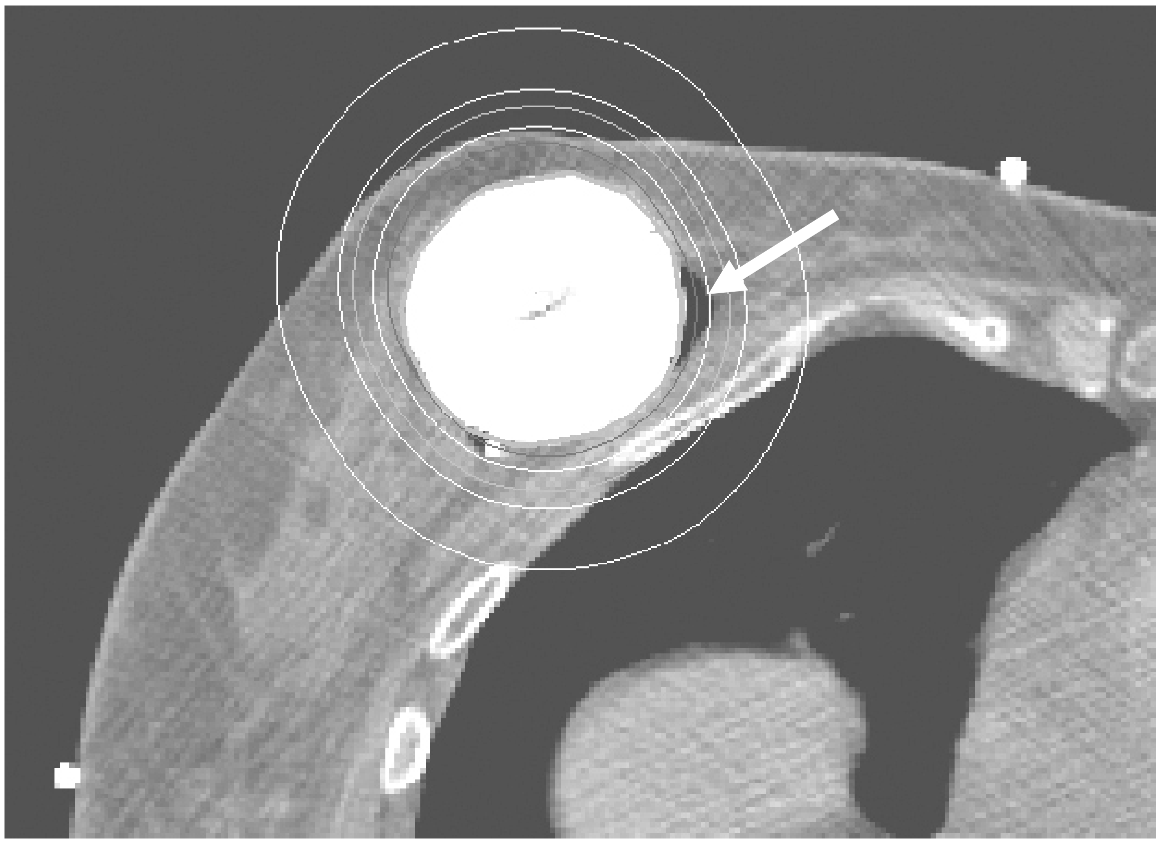
Calculation of the Effect of MammoSite Voids on the Equivalent Uniform Dose

Dan McDonald
Namratta Sehgal

The Problem

- During single balloon-catheter intracavitary HDR brachytherapy treatments, Air pockets often become trapped between the balloon surface and the cavity



The Problem

- These air pockets push tissue outside of the 1cm prescribed boundary
- The exact effect of these pockets on the dose distribution is unknown
- Creating a mathematical model allows for an estimation of the extent of this effect
  - This requires a formula for the dose at a distance r from the source, and a bubble model that allows for integration of this dose

Point Dose Model

- HDR brachytherapy dose rate give by

$$\dot{D}_p(r) = S_k \Lambda \phi(r) g(r) / r^2$$

- HDR brachytherapy dose usually calculated using tabulated values
- Radial dose function curve fit with a polynomial

$$g(r) = -0.0000251 \times \mathrm{r}^2 + 0.0013805 \times \mathrm{r} + 0.9908076$$

- Anisotropy factor assumed to be constant

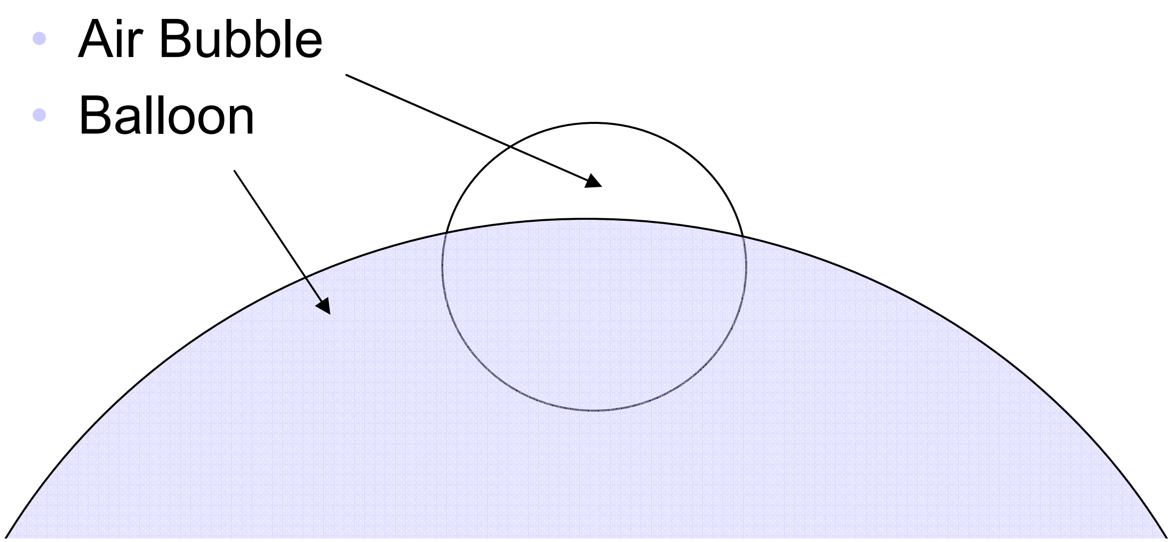
$$\phi_{\text{constant}} = 0.963$$

- Final formula for the dose rate at a point a distance *r* from the center of the balloon (for a specific activity)

$$\dot{D}_p(r) = \frac{40677.129 \times 1.108 \times 0.963 - 0.0000251 \times r^2 + 0.0013805 \times r + 0.9908076}{r^2}$$

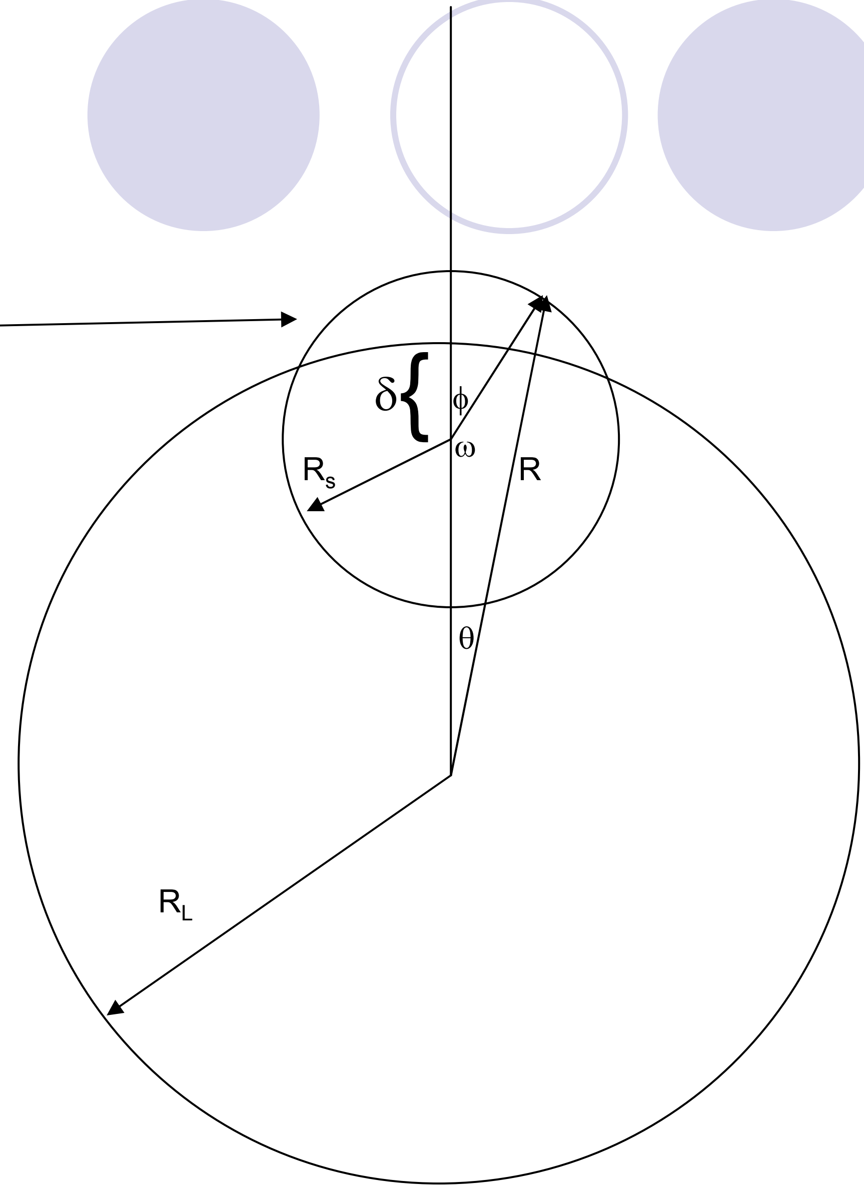
Bubble Model

- Assumptions
  - Balloon and air bubble
    - Spherical
    - Non-compressible



Bubble Model

- Bubble
- Balloon

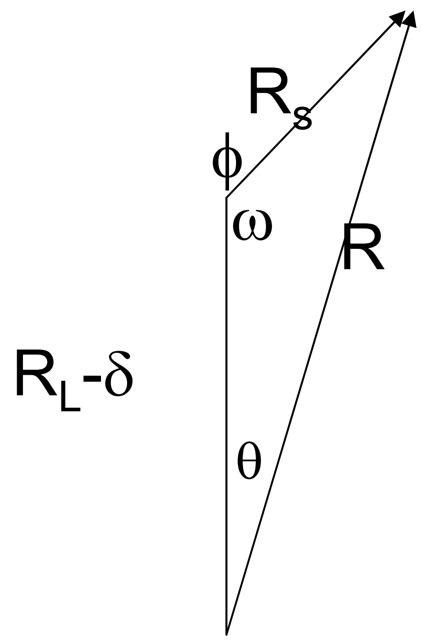


  - This model allows for ease of integration by relating the center to bubble radius R to the angle of integration θ

Bubble Model

- Relationship between R and θ

$$R = \sqrt{R_s^{\,2} - (R_L - \delta)^2 \sin^2(\theta)} + (R_L - \delta)\cos(\theta)$$



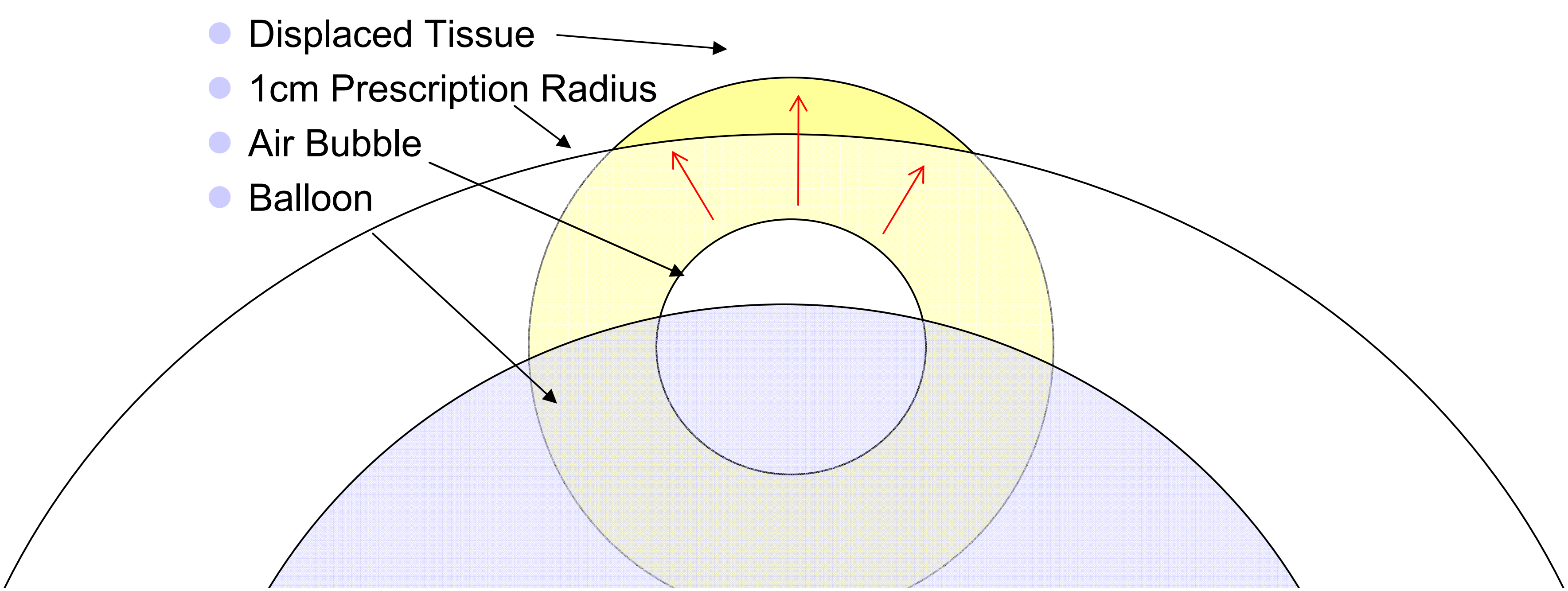
Bubble Model

- Using this relationship and the point dose model, dose can be integrated over the air bubble
- Depending on tissue model used, dose can be integrated over tissue displaced beyond 1cm prescription radius
- An ideal integral dose can be obtained by integrating the point dose model over a spherical shell
- This can be corrected for the presence of an air bubble by subtracting the integral dose given to the air bubble and adding the integral dose received by the tissue pushed beyond the 1cm prescription radius

Example

Choose Tissue Model

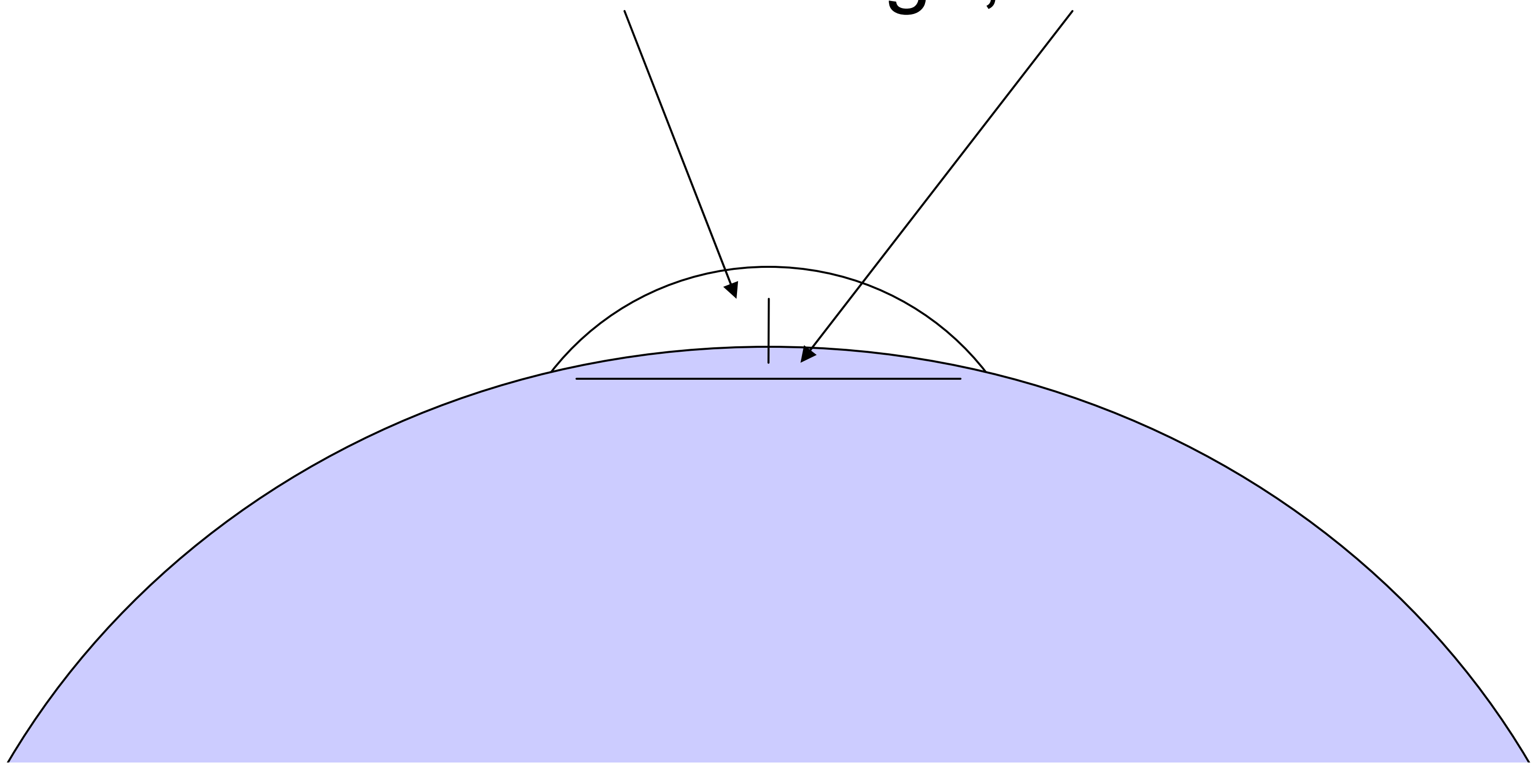
- Assume equal volume displaced
- Assume tissue to be displaced radially from the bubble



Example

Choose Treatment, Balloon Size, and Bubble Size

- Treatment ~ 3.4Gy to 1cm beyond balloon
- Balloon ~ 2cm Radius
- Air Bubble ~ 1.5mm high, 7.25mm wide



Example

Ideal Dose Calculation

Air Kerma Strength (U)	Dose Rate Constant (cGy/hU)
40677.129	1.108

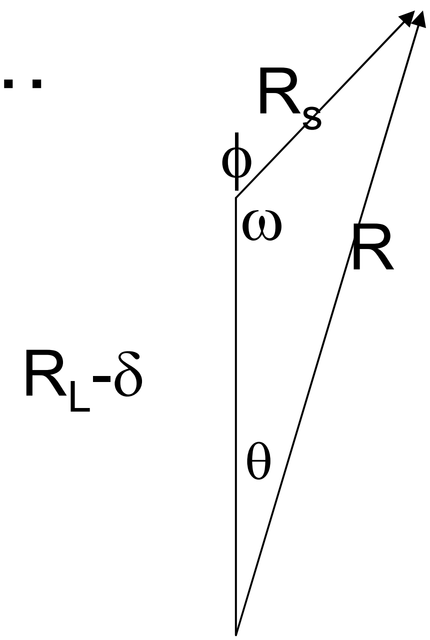
Balloon Radius (cm)	Treatment Margin (cm)	Total Radius (cm)	Treatment Time (m)
2	1	3	4.00
Integral Dose Rate (Gy cm^3/h)	Integral Dose (Gy cm^3)	Treatment Volume (cm^3)	EUD (Gy)
5798	386.4	79.59	4.85

- For a balloon radius of 2cm and prescription radius of 1cm the integral dose is 386.4Gy cm^3

Example

Calculation of Dose Lost to Bubble

- Integrate point dose formula in spherical coordinates over bubble volume
- For chosen dimensions…
  - R_s=5.14mm
  - R_L-δ≈16.36mm
  - θ=0 to 0.2 radians



$$R = \sqrt{R_s^2 - (R_L - \delta)^2 \sin^2(\theta)} + (R_L - \delta)\cos(\theta)$$

Example

Calculation of Dose Lost to Bubble

$$2\int_{0}^{2\pi}\int_{2}^{\sqrt{R_s{}^2-(R_L-\delta)^2\sin^2(\theta)}+(R_L-\delta)\cos(\theta)}\int_{0}^{0.2}\dot{D}(r)r^2\sin(\theta)\delta\varphi\delta r\delta\theta$$

- This integral provides a integral dose rate which must be multiplied by the treatment time in hours
- This gives an integral bubble dose of **56**Gy cm^3

Example

Calculation of Dose to Displaced Tissue

- The dose to the displaced tissue can be calculated in the same way as the dose to the bubble
- Dimensions for the displaced tissue determined based on chosen tissue model
- Using the model described earlier which expands the bubble until a volume of tissue approximately equal to the volume of the bubble is pushed beyond the 1cm prescription radius…
  - R_s=13.64mm
  - $R_L-\delta \approx$17.36mm
  - θ=0 to 0.225 radians
- Using the bubble integral with updated limits gives an integral dose for the displaced tissue of **46**Gy cm^3

Example

Calculation of Difference in Average Dose Caused by Air Bubble

- Without air bubble
  - Equivalent uniform dose (average dose over prescribed volume)

$$\frac{386.4 Gy\, cm^3}{\text{Treatment Volume}} = 4.85 Gy$$

- With air bubble
  - EUD

$$\frac{386.4 - 56 + 46 \quad Gy\, cm^3}{\text{Treatment Volume}} = 4.73 Gy$$

Example

Results

- For a balloon radius of 2cm and a treatment of 3.4Gy to a 1cm radius beyond the balloon, a bubble with a height of 1.5mm and a width of 7.25mm creates an average dose variance of approximately 2.5%

Conclusion

- Model allows for a variety of bubble sizes and tissue displacement models
- Limited by required use of spherical shapes
- Accuracy dependent on tissue displacement model
- Gives insight into the effect of voids on the EUD provided by single balloon-catheter intracavitary HDR brachytherapy treatments and allows for further study

Thanks!

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