Estimating the actual dose delivered by intravascular coronary brachytherapy using geometrically correct 3-D modeling

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Motivation

- Coronary arteries tend to develop new plaque accumulation after balloon angioplasty and stenting (*in-stent restenosis*)
- Irradiating the restenosed vessel segment decrease recurrent restenosis rate by 40-60%
- Common dose models for intravascular brachytherapy do not consider vessel curvature and eccentricity of catheter
In-Stent Restenosis:

(a) 
(b) 
(c) 
(d) 
(e)
In-Stent Restenosis (angio)

RAO

LAO
In--Stent Restenosis (angio)
In-Stent Restenosis (IVUS)
Angiography and IVUS

RAO View

LAO View

Stent and Irradiated Segment

IVUS Transducer
Position of the IVUS Catheter within Vessel

Consequences for Brachytherapy?
Questions:

- What is the impact of the vessel curvature on dose distribution?
- What is the impact of catheter eccentricity on dose distribution?
Dose Distribution in 0.5-mm Layers

Prescribed: 18.4 Gy @ 2 mm

Novoste Beta-Cath
12 Seeds ⁹⁰Sr/Y
Simulation: 60-180° Torus

κ = 120°
Dose Distribution 120° Torus

Location along Simulated Vessel [mm]
Dose Distribution 180° Torus

Location along Simulated Vessel [mm]
Results 120° Torus

Prescribed dose: 18.4 Gy
Eccentricity of the Catheter

Scenario Inner Curvature

Scenario Outer Curvature

40mm 16-Source Train within 60mm Simulated Vessel
120-degree Curved Vessel with Eccentric Catheter

Location along Simulated Vessel [mm]
Simulation Results:

- Vessel *curvature* increases the doses delivered to the inner bend.
- Catheter *eccentricity* biases dose distribution towards the closer wall.
- Effects may partially offset each other if the catheter is at an outer bend.
Questions (2):

- Impact *in-vivo*?
- How to generate an accurate 3-D model of the vessel segment?
- Angiography-IVUS Fusion
Principle of Data Fusion

IVUS  Angiography
Fusion Outline

- Matching of IVUS frames on 3-D path
  - Constant pullback speed
- Determination of absolute orientation
  - Differential geometry
  - Using IVUS catheter as landmark
- Mapping of pixel and contour data
In-Vivo Example
Finite-Element Mesh
Simulation

2 Segments
30mm train

Segment 1
Segment 2
Doses

1. Adventitia
2. Lumen
Geometrically Correct Model

- Lumen/Plaque
- Media/Adventitia
Simplified Tubular Model

- GY0 - Lumen/Plaque
- GY1
- GY2
- GY3 - Media/Adventitia

Dose [PD=18.4Gy]

Frame

0 10 20 30 40 50 60

20 40 60 80 100 120 140 160 180
## In-Vivo Results

<table>
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<tr>
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<tbody>
<tr>
<td></td>
<td>(mean±SD)</td>
<td>(mean±SD)</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>n = 10</td>
<td>n = 10</td>
<td>n = 10</td>
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<tr>
<td>Lumen/Plaque</td>
<td>34.70 ± 11.93</td>
<td>31.66 ± 5.11</td>
<td>8.76</td>
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<td></td>
<td>LAD n = 3</td>
<td>LCX n = 2</td>
<td>RCA n = 5</td>
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<tr>
<td>Intermediate 1</td>
<td>26.71 ± 8.76</td>
<td>24.85 ± 4.14</td>
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<td>Intermediate 2</td>
<td>21.28 ± 7.41</td>
<td>19.92 ± 3.84</td>
<td>6.39</td>
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<tr>
<td>Media/Adven.</td>
<td>17.31 ± 6.72</td>
<td>16.18 ± 3.71</td>
<td>6.52</td>
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<td>3.82 7.35 7.86</td>
<td>3.95 6.70 7.74</td>
<td>8.38</td>
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Discussion

- Vessel curvature and catheter eccentricity influence dose distribution of beta emitters
- Simplified models underestimate average doses as well as dose variability as compared to geometrically correct 3-D models
- No gold standard available
- However, tendencies shown in this study should prevail regardless of absolute values
Future extensions:
- Plaque characterization
- Monte-Carlo simulation
- 4-D model by ECG sorting
- ...
Conclusions

- Dose-delivery models for intravascular brachytherapy should consider vessel curvature and eccentricity of catheter.
- Centering of the catheter of major interest to ensure prescribed dose is actually delivered homogeneously.
- Our method may help improving both dosing models and delivery systems.