Influence of removing of the US-probe and/or further implant alterations on the Quality of 3D US-Based Prostate HDR Brachytherapy Treatment

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Introduction: Clinical Procedure at Offenbach Clinic
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Materials

This Study is based on the following image sets of 15 Monotherapy patients:

[1] Clinical 3D image set
   Patient irradiation plan is based on clinical image set (live plan: reference):
   *30 ml of water within the US-probe overlay
   Acquisition of images for this image set is made just after finalization of the implantation.

[2] 3D image set
   The amount of water within the US-probe overlay was reduced from 30 to 20ml

[3] 3D image set
   The amount of water within the US-probe overlay was reduced from 30 to 10ml

[4] 3D image set
   The whole amount of water is taken out from the US-probe overlay

The mean volume of prostate (PTV) for the 15 cases is 39.2cm³ with minimum volume of 25.8cm³ and maximum of 61.1cm³.
In our procedure, the *reference (R-) plan* (1) is based on the 3D image set acquired after all needles were implanted.

The water quantity of 30ml was inserted within the contact condom lying over the US-probe at the beginning for all R-plans. Prostate and OARs’ contouring is done by radiation oncologist. Needle reconstruction and finally the treatment plan are prepared by medical physicist.

The three additional image acquisitions were done:
- by reducing the water quantity to 20ml (2),
- 10ml (3) and 0ml (4) respectively.

Based on these image sets, the PTV and OARs were contoured, needles were reconstructed.

The active dwell positions and the dwell times were calculated for the reference-plans (1) in order to achieve the optimal dose distribution. After that they were imported in reconstructed needles of plans (2), (3) and (4).
Anatomy alteration

Maximum shift in dorsal prostate region is 5.8 mm and ventral: 2.8 mm.

By urethra, the measured displacement was significantly smaller than that of prostate with a maximal shift of 3.3 mm.

Maximum shift of rectum at the reference plane was 5.3 mm.
The largest displacement of needles was found on the base plane in dorsal prostate region, between acquisitions (1) and (4) as expected: \textbf{4.85mm}.

### Needle displacement at base, reference and apex plane

<table>
<thead>
<tr>
<th>Plane</th>
<th>Case Nr.</th>
<th>ventral</th>
<th>dorsal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>(1)-(2)</td>
<td>1.0±0.4</td>
<td>1.4±0.5</td>
</tr>
<tr>
<td></td>
<td>(1)-(3)</td>
<td>1.6±0.6</td>
<td>2.4±0.8</td>
</tr>
<tr>
<td></td>
<td>(1)-(4)</td>
<td>2.1±0.5</td>
<td>3.1±0.8</td>
</tr>
<tr>
<td>Reference</td>
<td>(1)-(2)</td>
<td>0.6±0.4</td>
<td>0.9±0.5</td>
</tr>
<tr>
<td></td>
<td>(1)-(3)</td>
<td>1.1±0.5</td>
<td>1.6±0.7</td>
</tr>
<tr>
<td></td>
<td>(1)-(4)</td>
<td>1.4±0.5</td>
<td>1.9±0.7</td>
</tr>
<tr>
<td>Apex</td>
<td>(1)-(2)</td>
<td>0.2±0.1</td>
<td>0.6±0.3</td>
</tr>
<tr>
<td></td>
<td>(1)-(3)</td>
<td>0.7±0.4</td>
<td>0.9±0.5</td>
</tr>
<tr>
<td></td>
<td>(1)-(4)</td>
<td>0.9±0.5</td>
<td>1.2±0.6</td>
</tr>
</tbody>
</table>
Dose-Volume-Histograms

Prostate

The changes of $D_{90}$ between the plans (1)-(2) is not significant ($p=0.36$) and between (1)-(3) and (1)-(4) are significant ($p<0.05$), at the 0.05 significance level. Mean value for the $D_{90}$ of prostate, for the R-plans (1) is $(106.3 \pm 1.9)\%$ of Dref, plans (2) : $(105.5\pm2.4)\%$, plans (3) : $(104.7\pm2.3)\%$, and for plans (4) with empty US-probe overlay it is $(104.4\pm2.4)\%$.

In all cases the value of $D_{90}$ remains within our clinical protocol.

For $V_{100}$, these values are as follows; (1): $(95.0\pm1.4)\%$, (2) $(94.0\pm1.8)\%$, (3) $(93.3\pm1.7)\%$ and (4): $(93.0\pm1.7)\%$. The changes of $V_{100}$ between the plans (1)-(2) is not significant ($p=0.11$) and between (1)-(3) and (1)-(4) are significant ($p<0.05$), at the 0.05 significance level.
Dose-Volume-Histograms

Rectum

Water quantity within the US-probe overlay

$D_{10}$ for the case of:
- (1) 30ml
- (2) 20ml
- (3) 10ml
- (4) 0ml

$p_{12} = 0.856$
$p_{13} = 0.699$
$p_{14} = 0.589$

$D_{2cm}$ for the case of:
- (1) 30ml
- (2) 20ml
- (3) 10ml
- (4) 0ml

$p_{12} = 0.156$
$p_{13} = 0.010$
$p_{14} = 0.002$

$D_{0.1cm}$ for the case of:
- (1) 30ml
- (2) 20ml
- (3) 10ml
- (4) 0ml

$p_{12} = 0.973$
$p_{13} = 0.099$
$p_{14} = 0.024$
Dose-Volume-Histograms

Urethra

\[ p_{12} = 0.617 \]
\[ p_{13} = 0.775 \]
\[ p_{14} = 0.791 \]

Water quantity within the US-probe overlay

\[ D_{10} \text{ for the case of:} \]
- 30ml
- 20ml
- 10ml
- 0ml

\[ D_{0.1cm} \text{ for the case of:} \]
- (1) 30ml
- (2) 20ml
- (3) 10ml
- (4) 0ml

\[ p_{12} = 0.795 \]
\[ p_{13} = 0.569 \]
\[ p_{14} = 0.591 \]
COIN and External Index (EI)

In Baltas et al.* a **conformal index COIN** was proposed as a measure of implant quality and dose specification in brachytherapy. COIN focusing on the target volume PTV is defined as:

$$COIN = c_1 \cdot c_2 \cdot c_3$$

The coefficient $c_1$ is the fraction of the PTV that is enclosed by the prescription dose.

The coefficient $c_2$ is the fraction of the volume encompassed by the prescription dose that is covered by PTV. It is a measure of how much tissue outside the PTV is covered by the prescription dose.

$$c_3 = \prod_{i=1}^{N_{OAR}} \left[ 1 - \frac{V^i_{OAR} (D > D^i_{limit})}{V^i_{OAR}} \right]$$

where $N_{OAR}$ is the total number of OARs, $V^i_{OAR}$ is the volume of the i-th OAR, $D^i_{limit}$ is the dose limit defined for the i-th OAR, and $V^i_{OAR} (D > D^i_{limit})$ is the volume of the i-th OAR that receives a dose that exceeds the dose limit $D^i_{limit}$.

While the coefficients $c_1$ and $c_2$ depend on the dose value under consideration, the coefficient $c_3$ depends only on the dose limits defined for each of OARs.

*The ideal situation is $COIN = c_1 = c_2 = c_3 = 1$. COIN assumes in this form that the PTV, the OARs and the surrounding NT are of the same importance.

For our study, we have compared COIN values including OARs, for the reference/prescribed dose to PTV.

The **external volume index (EI)** is the ratio of the normal tissue volume outside of the PTV that receives a dose equal to or greater than the reference dose to the volume of the PTV. Using the previously described coefficients $c_1$ and $c_2$, it can be calculated as:

$$EI = \frac{c_1}{c_2} - c_1$$
The COIN values for all R-plans (1) are above 0.80, while for the plans (2), (3) and (4) some of the COIN values drop below 0.8. The minimum COIN value was: 0.72 for plans (3) and (4) while their R-plan COIN was 0.84.

As it can be noticed from Table 4, the COIN coefficient $c_3$ has negligible influence on drop of COIN. The observed changes are statistically insignificant.

Main responsibility for COIN decreased value have the factors $c_1$ and $c_2$, which means that the coverage of PTV with reference dose has been decreased and the volume of the healthy tissue outside of PTV covered with this dose has increased.
From 30ml to empty US-probe overlay

30ml – slice between base and reference plane

0ml – corresponding plane
From 30ml to empty US-probe overlay

30ml – reference plane

0ml – corresponding plane
From 30ml to empty US-probe overlay

30ml – slice between reference plane and apex

0ml – corresponding plane
From 30ml to empty US-probe overlay
From 30ml to empty US-probe overlay

What happens when the US-probe is taken out? Our observation from CT images made with removed S-probe (2003-2004) show that the needles are strongly moved towards the Urethra. The plan quality was reduced, as the patient needed to be moved from OP-table.
Conclusions

For high modulated plans as those in HDR Brachytherapy even such small shifts result in statistically significant dosimetric changes. We gave a good idea of what consequences it makes on a dose distribution it makes if the US-probe is removed/manipulated in any way after the image acquisition and before the radiation delivery.

Our results demonstrate that quality assurance procedures have to be clinically implemented to guarantee anatomy and implant stability of the order of 1mm. This can only be realized without any manipulation of the implant and anatomy as done in the case of removing the US-probe before treatment delivery.

In K.M. Kälkner et al.* “The use of a PWDK contributes to an increase in the distance between the prostate and the rectum. However, when removing the water, there is movement of the prostate despite the needles remaining in place, implying the need for utilizing an on-line dose-planning or very careful in vivo dosimetry.”… unpredictable situation.

References


