Applicator reconstruction in cervix brachytherapy

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General remarks

Pre-clinical applicator commissioning is an important step in quality assurance of applicator reconstruction. During this process the location of dwell positions is found in relation to each other or in relation to reference point in the applicator, e.g. the distance from the tip of the tandem applicator to the first dwell position. Applicator commissioning should include CT scan of the applicator with a slice thickness of preferably 1mm, so that the geometry of the source channel can be visualized in relation to the outer surface of the applicator. Autoradiography is also an important step in applicator commissioning in order to verify the source positioning.

The geometry of the applicator, or more correctly the source dwell positions, can be stored as library files and later used clinically. The procedure for importing these library files is critical. It is important to realize that even a correctly reconstructed applicator positioned wrongly in the 3D study will lead to an incorrect estimate of the dose distribution in the patient.

The applicator can also be reconstructed by digitizing the track of the source directly in the acquired images. Using this method it is important to correctly identify the first dwell position. If this position is located between two images a correction should be applied. When transversal (or para-transversal) images are used a lateral view is a valuable tool to determine the magnitude of this correction. Even if the first dwell position is correctly identified it is also important to correctly digitize the track of the source. By digitizing a curved applicator in several images there is an inherent risk of reconstructing a too long or too short track. When many points are used a tagged shaped applicator is often the result. Consequently the dwell positions will be located wrongly with a potential result of inaccuracies in the dose distribution.

Today TPSs in brachytherapy offer the possibility of producing so called multiplanar reconstruction images. If the relevant part of an applicator, e.g. a ring applicator, could be visualized in one such image, the problems with the direct reconstruction described above, could be avoided.

Reconstruction in CT images

It is easy to visualize the track of the source in CT images. Often the lumen of the applicator is well visualized and this means that a markerstring is not always necessary. But anyhow the locations of the dwell positions inside the lumen have to be known. Some x-ray catheters may produce artifacts in the CT images resulting in larger uncertainties in the reconstruction process.

Hellebust et al analyzed the impact of the applicator orientation on the calculated dose around a reconstructed ring applicator set using CT imaging (Hellebust et al, Reconstruction of a ring applicator using CT imaging, Phys Med Biol. 2007 Aug 21;52(16):4893-904). They also included

an analysis of the impact of the reconstruction method used. Their results showed that it was not possible to identify one applicator orientation that gave lower uncertainties with regard to the calculated dose around the applicator. Moreover they found that library reconstruction method gave significant smaller standard deviations than direct reconstruction. However, it is important to point out the standard deviation of the calculated dose for all orientations and all reconstruction methods were less than 4%. They concluded that using CT for applicator reconstruction will result in reconstruction uncertainties that are considerable smaller compared to other uncertainties in brachytherapy.

Reconstruction in MR images

The challenge in MR images is to localize the source channel since conventional markers used for x-ray and CT cannot be used in MRI. Special MR markers like catheters containing a fluid CuSO4 solution or water are alternatives although the signal from these MR markers can be faint in T2-weighted images. Depending on the type of applicator, treatment planning system, and options for imaging, there are several possibilities for reconstruction procedures: 1) Reconstruction directly on T2 weighted images based on MR markers, 2) Reconstruction on T1-weighted MR images, 3D MR acquisitions, CT images, or x-rays, with subsequent merging of this information with the T2 images, or 3) For rigid applicators, the reconstruction of the applicator could be performed in relation to the outer contour of the applicator or in relation to some reference points that are visible in T2 images. Slice thickness is an important parameter which has direct impact on the precision of reconstruction, and it is recommended to perform reconstruction in image series obtained with a slice thickness less than or equal to 5 mm.

Applicator reconstruction catalogue

As indicated above there are many different approaches to MRI applicator reconstruction. In the following, a number of reconstruction procedures are described in detail for some of the common applicators and treatment planning systems.

The document contains dimensions of the different applicators as they have been measured in the different departments. There are minor differences between the applicator dimensions measured in different institutes, and it is emphasized that every department has to characterize their applicators as part of their own QA procedures. The applicator dimensions in this document should only be used as reference values.

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Varian plastic tandem ring applicator

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Geometry of applicator

Position of x-ray markers and source channel relative to outer surface of applicator

An example of the plastic ring applicator geometry is shown in figure 1 for a ring with a 60mm cervical sleeve. The distance from the source channel in the ring to the surface of the ring is 3mm without cap and 5mm with cap. This means that point A should be positioned 23mm or 25mm above the source channel for ring without or with cap, respectively.





Figure 1. Geometry of applicator and source channel

Source positioning in ring

Due to slack of the source cable in the ring, the source does not position according to the x-ray markers in the ring. This problem is recognised by Varian, and has been described for the titanium ring (in Varisource afterloader) in "Customer Technical Bulletin" CTB-VS-413B in 2005 - see figure 2. However, in a "Medical Device Recall" of 03/07/2008 Varian concludes that all ring applicators have to be characterised individually by the users due to differences from ring to ring and also due to changes over time.







Figure 2: Source wire in second treatment position with snaking of the wire in the straight Figure 2. Customer Technical Bulletin'' CTB-VS-413B

At Aarhus University Hospital we are applying the same correction for all rings. Our experience is that the first 4 mm retraction of the cable just straightens the wire and does not lead to retraction of the source. This can be compensated for by defining the end of the source channel 4 mm beyond the real end of the source channel, and then apply an offset of 4 mm in the dose planning procedure. At Aarhus University Hospital, a library applicator with such a "virtual end" has been introduced into Brachyvision – see figure 3. At institute of Oncology Ljubljana the slack has been measured to be 3mm.

The end of the inner tube is different for each ring diameter: Ø26: 298dgr Ø30: 296dgr Ø35: 307dgr



Figure 3. Library applicator for Ø30 applicator on a) CT and b) MR

Reconstruction procedure

<u>Procedure at Aarhus University Hospital (Brachyvision TPS) – also described in Haack et al.</u> <u>"Applicator reconstruction in MRI 3D image based dose planning of brachytherapy for cervical cancer", Radiother Oncol,2009 in press</u>

Imaging and contrast in applicator:

Paratransversal T1 (3mm slice spacing) and T2 (5mm slice spacing) are obtained. The sequences are registered on scanner coordinates when possible. However, if internal movement has happened in between the T1 and T2 sequences a manual registration on the applicator is performed. In-house produced dummy catheters containing CuSO4 are inserted into the source channels during MRI acquisition. The catheters are produced using plastic tube (Portex polythene tubing, Smiths Industries, Kent) with outer and inner diameters of 1.22 mm and 0.76 mm, respectively. The tubes are filled with a CuSO4 solution of 2.08 g/l. The catheters are sealed in both ends by heating. The catheters are visualised on T1 and also faintly on T2 weighted images. Catheters are renewed about every 3 months due to evaporation of fluid.

Reconstruction:

Tandem and ring are reconstructed individually by importing library applicators. Multiplanar reconstructions of the T1W images are used in this process, utilizing the superior applicator visualization due to pixel size and slice thickness as compared to the T2W images.

The tandem is visualized in the sagital and coronal reconstructions. Lateral and anterior-posterior positioning is determined from the signal void. The position of the tip of the tandem is identified from the signal void, and the end of the source path is defined 3mm below the tip according to the thickness of the tandem tip.

The ring source channel is positioned according to the depth of the source channel below the ring surface – either 3mm (no cap) or 5mm (cap) - as specified by the vendor and verified during applicator commissioning. The depth is verified by comparing to the position of the CuSO4 signal in both T1W and T2W images. The rotation of the ring is determined from the position of the ring



Figure 4. Ring applicator visualisation. Different columns correspond to 1) CT phantom, 2) MR phantom, 3) T1 weighted in patient, 4) T2 weighted in patient.

guide tube in the vagina as visualized by CuSO4 signal. The CuSO4 signal in the ring cannot be used to determine the rotation of the ring – this would be far too uncertain since the tip of the CuSO4 catheter cannot be assumed to indicate the end of the source channel due to evaporation of liquid in the very thin catheter and due to varying thickness of the end of the .

Procedure at Institute of Oncology Ljubljana (Brachyvision TPS)

Imaging and contrast in applicator:

Before the applicator insertion, in-house produced single-time use water markers are glued on the ring guide tube.

Paratransverse (aligned with the plane of the ring) T2 fast-spin echo (FSE) sequence (0.6x0.6 mm pixel size, 3.9 mm slice spacing) and T2 fast-recovery fast-spin echo (FRFSE) sequence (1 mm isotropic voxels) are obtained. On both sequences, water marker is clearly visible.

The sequences are registered on scanner coordinates and checked for any applicator shifts, which may occur between the two sequences. If the shift is equal or larger than 1 mm, manual registration correction is performed.

Reconstruction:

Tandem and ring are reconstructed individually by importing library applicators. FSE image slices are used for in-plane reconstruction, while multiplanar reconstruction of the FRFSE images is used for interslice reconstruction, utilizing the smaller slice thickness of the image.

The ring source channel is positioned according to the depth of the source channel below the ring surface – either 3mm (no cap) or 5mm (cap). The rotation of the ring is determined at 286° from the position of the water marker (see figure 5). The true end of the applicator is at 296° (for the Ø30 ring). The overrotation of 10° corresponds to a slack of 3mm.



Figure 5. Water marker and rotation of ring

Varian titanium tandem ring applicator

Kari Tanderup (Aarhus University Hospital) Gerry Lowe and Rachel Wills (Mount Vernon Hospital)

Geometry of applicator

Position of x-ray markers and source channel relative to outer surface of applicator

An example of the titanium ring applicator geometry is shown below for a ring with a 60mm cervical sleeve. For this applicator system there are two caps: black and white. The distance from the source channel in the ring to the surface of the ring is 5mm and 7.5mm for black and white cap, respectively, according to Varian. This means that point A should be positioned 25mm or 27.5mm above the source channel. The thickness of the top of the sleeve is 0.4mm according to Varian. At Aarhus University Hospital autoradiography indicated a thickness below 1mm. At Mount Vernon Hospital the thickness has been assessed to be around 1mm by measuring from the end of a dummy wire to the outer end of the tandem (fig 1). On figure 2 the applicator can be seen as it appears on CT. Be aware that the titanium material looks much thicker than 0.4-1mm on CT – due to the strong attenuation of metal, CT cannot be used to assess the wall thickness of metal applicators.



Fig. 1. Thickness of tip of tandem as measured by Mount Vernon Hospital



Fig. 2. Titanium applicator on CT

Source positioning in ring

Due to slack of the source cable in the ring, the source does not position according to the x-ray markers in the ring. This problem is recognised by Varian, and has been described for the titanium ring (in Varisource afterloader) in "Customer Technical Bulletin" CTB-VS-413B in 2005 - see figure 3. However, in a "Medical Device Recall" of 03/07/2008 Varian concludes that all ring

applicators have to be characterised individually by the users due to differences from ring to ring and also due to changes over time.

At Aarhus University Hospital we are applying the same correction for all rings. Our experience is that the first 3.5mm retraction of the cable just straightens the wire and does not lead to retraction of the source. This can be compensated for by defining the end of the source channel 3.5mm beyond the real end of the source channel, and then apply an offset of 3.5mm in the dose planning procedure. At Aarhus University Hospital, a library applicator with such a "virtual end" has been introduced into Brachyvision – see figure (4). The outer end of the titanium ring has an angle of 15° with respect to the ring guide tube.







Fig. 3. From "Customer Technical Bulletin, Varian, 2005"



Fig. 3. Titanium ring on a) CT and b) MR

Reconstruction procedure

Procedure at Aarhus University Hospital (Brachyvision TPS) – also described in Haack et al, "Applicator reconstruction in MRI 3D image based dose planning of brachytherapy for cervical cancer", Radiother Oncol,2009 in press

Imaging and contrast in applicator:

Paratransversal T1 (3mm slice spacing) and T2 (5mm slice spacing) are obtained. The sequences are registered on scanner coordinates when possible. However, if internal movement has happened

in between the T1 and T2 sequences a manual registration on the applicator is performed. Dummy catheters containing CuSO4 do not produce any visible signal due to susceptibility artifacts of titanium.

Reconstruction:

There is a susceptibility artifact pattern from the titanium material around the applicator. In coronally reconstructed images there are bright regions to the left and right of tandem - figure (b) below. In the region of the cap there is a bright artifact just where the titanium source channel recedes into the ring cap – figure (4f).



Fig. 4. Titanium ring as it appears in coronal and transverse views: a + c phantom on CT, b + f phantom on MR, c + g patient on T1 weighted MR, d + h patient on T2 weighted MR

Tandem and ring are reconstructed individually by importing library applicators. Multiplanar reconstructions of the T1W images are used in this process, utilizing the superior applicator visualization due to pixel size and slice thickness compared to the T2W images.

The tandem is visualized in the sagital and coronal reconstructions. Lateral and anterior-posterior positioning is determined from the signal void. The position of the tip of the tandem is identified from the titanium artefacts - figure (4b), (4c) below -, and the end of the source path is defined 0.4 mm below the tip according to the thickness of the tandem tip.

The ring source channel is positioned according to the depth of the source channel below the ring surface – either 5mm (black cap) or 7.5mm (white cap).

At Aarhus University Hospital, it has been measured that there is a shift of signal at the level of the titanium ring (due



Fig. 5 Susceptibility artefacts in ring region on MR (upper panel) as compared to CT (lower panel)

to susceptibility differences). The signal void of ring cap is shifted by 1 mm to the right - in the direction of the read gradient (fig 5). This phenomenon can only be seen in image sequences with a small slice thickness of 1mm. In sequences with larger slice thickness the signal is blurred and the shift can be considered as negligible during applicator reconstruction.

The rotation of the ring can be determined from the artifact produced by the ring tube where it enters the ring. However, this artifact is not very bright (figure (f) and (g) below), and it happens that it cannot not be distinguished due to patient motion during MR acquisition – see paragraph below (Mount Vernon procedure) for an alternative method where ultrasound gel is used as contrast medium. It would also be a possibility to insert a catheter containing water into the cap – see paragraph on the Ljubljana approach to reconstruction of the Varian plastic ring.

Procedure at Mount Vernon Hospital (Brachyvision TPS)

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Imaging:

Our MR scanner has previously been validated to provide a volume of 14cm x 14cm x 14cm inside which geometric image distortion is less than or equal to 2mm, for the coils and sequences used. Care is taken to ensure that the applicator set is within this volume, which is defined relative to the room lasers. It is recommended that this validation is performed individually for each scanner, coil and sequence to be used.

Paratransversal T2-weighted MR images with 3mm slice spacing are obtained. Aqueous gel has been inserted, in theatre, into the spacer cap on the ring and also into the cervical sleeve.

The MR images are acquired using two concatenations.¹ If there is patient movement, therefore, this will become easily visible on a coronal view of the images (figure 6). This will alert the physicist to the presence and magnitude of movement effects which could affect the accuracy of applicator reconstruction. In this case, the reconstruction can proceed using the concatenation which includes a slice through the ring. The effect and magnitude of the patient movement will need to be taken into

account when volumes are defined on the MR images. It is sometimes better to proceed using just one concatenation; however this will render 6mm between slices and the best procedure needs to be evaluated on a patient-by-patient basis.

If there is doubt as to the interpretation of the MR images (for example because of severe patient movement artefacts), or if there are interstitial needles to be reconstructed², a CT image set will be acquired with 3mm slice spacing. The CT will be registered to the MR images using reference points placed with respect to the applicators themselves.



Figure 6: Extreme motion artefact visualised as spatial mis-registration between MR concatenations.

¹ Alternate slices are acquired first, and then the remaining slices afterwards.

² At Mount Vernon we do not currently reconstruct interstitial needles from MR images alone; this is however the subject of current work.

Reconstruction:

In the para-cranio-caudal direction, the levels of the top and bottom of the spacer cap are visualised. There will be some partial voluming of the signal across adjacent slices, but with prior knowledge of the thickness of the cap this can be assessed by the observer and the levels of the top and bottom of the cap established in the coronal view (figure 7). At Mount Vernon, the black spacer cap is measured as 15mm from top to bottom, and the white spacer cap as 17.5mm from top to bottom. Again, these values should be verified at each centre.

The level of the ring in this view can then be inferred from prior measurement on the applicator relative to the front (distal) end of the spacer cap: at Mount Vernon this has been measured as 4.8mm (black spacer cap) and 7.3mm (white spacer cap), although these values should be confirmed at each site by specific measurement. Be aware that MR images of the titanium applicators can contain artefacts that are potentially misleading. Careful site-specific measurements are recommended.



Figure 7: Establishing the levels of the top and bottom of the spacer cap.



Figure 8: Verification of the distal end of the tandem.

The tandem and ring applicator reconstructions can then be added to the plan, with the ring at the correct para-cranio-caudal level, using geometry pre-defined in an applicator library within the TPS. This defines both applicators together, and therefore the para-cranio-caudal position of the tandem will be defined by the ring.³ It is recommended that each centre generate its own applicator library with reference to the actual applicator set being used. At Mount Vernon this was done by performing high-resolution CT imaging of the applicator sets in water and in air (with slice spacing approximately 1mm).

The position of the outer distal end of the tandem can be verified by looking for the signal from the aqueous gel inserted into the cervical sleeve. Prior measurements show that the reference position of 1300mm in the tandem (the tip of the red arrow in brachyvision to which the reconstruction should be aligned) should be 1.4mm back from the outer distal end of the applicator (once again, this

³ This assumes that the tandem and ring are correctly located together in theatre. Care is sometimes needed during the procedure to ensure that this is the case.

measurement should be performed at each centre and for each applicator). Because of the partial volume effect caused by the 3mm MR slice spacing, this measurement is approximate and best used only as a verification of the tandem position (figure 8).

In order to align both applicator reconstructions para-transaxial the plane, we have in characterised the artefact pattern visualised on the MR from the tandem. The orientation of the pattern will depend on the direction of the phaseencoding gradient but figure 9 shows the position of the tandem (as determined by phantom measurements) relative to the artefacts seen on MR. Since both the tandem and ring applicator reconstruction are positioned together, having been derived from the applicator library with the TPS, this procedure will also line up the ring reconstruction.

It is however important to use slices close to the ring to perform this. This is because it is occasionally observed, especially for the longer



Figure 9: Para-transaxial alignment of the tandem applicator. The red X marks the position at which to place the reconstruction.

tandem applicators, that the tandem is flexed slightly by the patient anatomy; using a slice too far away from the ring applicator will introduce a translational error if this has happened.

The ring reconstruction is then aligned rotationally in the para-transaxial plane, using the aqueous gel which marks the outside of the distal end of the ring (figure 10).



Figure 10(a): Placement of aqueous gel inside the spacer cap before the ring is assembled in theatre.





Without aqueous gelWith aqueous gelFigure 10(b): Imaging of the ring without and with aqueous gel



Figure 10(c): Reconstruction of the end of the ring.

At Mount Vernon, Varian PNL-GM-CR 30281 (August 2008) has been implemented. This advises that each ring applicator should be characterised, and that this process should be frequently repeated (for example, when a new source is installed) to ensure positional accuracy of the reconstruction. At Mount Vernon, at the time of writing, the ring is reconstructed with the 1300mm reference mark (the tip of the red arrow in brachyvision) set at the outer edge of the physical ring (that is, the position of the aqueous gel (figure 10(c))) and an origin of 2mm applied in the planning system. The rotational position of the ring reconstruction can be checked using the visualised ring tube as it enters the ring, as described above in the Aarhus University Hospital procedure. In addition, if CT



Figure 11: Flexing of the tandem applicator in a patient.

imaging has been performed, and the caudal field of view is large enough, the locating bracket connecting the tandem to the ring applicator can be visualised on both modalities and provides a further check that all is well.

Finally, any flexing of the tandem is accounted for by moving the distal end of the tandem reconstruction to overlie the visualised position (figure 11).

Nucletron Standard and Fletcher CT/MR tandem-ovoid applicator

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I. Geometry of applicator

Position of x-ray markers and source channel relative to the outer surface of the applicator

An example of the Standard CT/MR tandem-ovoid applicator is shown below. Ovoid pairs with a lateral dimension of 20, 25 and 30 mm are available. The distance from the source channel in the ovoids to the surface of the ovoids in the direction of the intrauterine tube is 10 mm, irrespective of the lateral dimension (see figure). This means that point A should be positioned 30 mm above the source channel along the direction of the intra-uterine tube.





Standard CT/MR tandem-ovoid applicator

Source positioning in the intra-uterine tube and ovoids

A schematic diagram of the intra-uterine and ovoid tubes is given in the figure below. The values for the applicator dimensions are extracted from a technical bulletin from Nucletron. It should be emphasized however that these values are nominal. Minor deviations can be observed in individual applicators. It is therefore of utmost importance that each centre verifies the dimensions that are important for a correct reconstruction in the treatment planning system.



Some examples of such tests are described here. At the University Hospital Gasthuisberg in **Leuven**, the applicator specifications were verified on digital x-ray images of the left and intrauterine channel containing the PDR dummy markers (see figure). The sleeve thickness was measured to be 1 mm in the ovoidal channels and 2 mm in the IU source channel, which corresponds to the values specified by the manufacturer. The distance from the outer applicator tip to the first source position however was found to be 5 mm and 6 mm for the ovoids and intrauterine tube respectively. The distance from the marker tip to the first source position, located in the middle of the first dummy marker, is found to be 4 mm (i.e. half the length of the dummy marker).



In **Utrecht** 3 different applicator sets are used (Standard CT/MR Applicator Set, Fletcher CT/MR Applicator Set, Utrecht CT/MR Applicator Set). From the x-ray images slightly different distances for the different applicator sets were found. The reconstruction is made along the core of the channel, although from the x-ray images it can be seen that the dummy markers are not always at the core. A combination of x-ray image and autoradiograph of a stepping source for one applicator set shows the uncertainty between marker positions and source dwell positions.

Distances from applicator tip to first source dwell position (SDP) were measured for each set: This is either 6 mm for the ovoids/ 7 mm for the intrauterine tandem or 7 mm for the ovoids / 8 mm for the tandem.

The angle between the ovoid main axis and the long end of the channel is 120 degree. Distance from the intersection point to the first dwell position is 19 mm.

Some illustrations: x-ray image of our Utrecht CT/MR Applicator set, and a template of the ovoid of this set.







Combination of x-ray and autoradiograph of an ovoid and tandem channel of a Fletcher CT/MR Applicator set, used to check if the first dummy position relates to the source dwell position.

II. Reconstruction procedure

Procedure at the University Hospital Gasthuisberg in Leuven

A. TPS: Nucletron-Plato BPS v14.3.5 – EVAL 3.1

Imaging and contrast in applicator

For delineation of the organs of interest, 4 mm transversal, para-sagittal and para-coronal fast spin echo (FSE) T2-weighted MR images are acquired on a 1.5T Siemens Sonata scanner (TE = 120 ms, TR = 6000 ms, slice thickness 4 mm and no interslice gap). We have tried to visualise the source channels on MR-T2 images by inserting plastic tubes (outer diameter 1.0 mm) filled with water (see figure). It was possible to identify the source channels by an increased signal in those slices where the tubes were perpendicular to slice plane (parallel to the scanning direction). However, in those slices where the tubes curve away the signal was too low, even with increased scanning times. So, in the crucial areas where source channel identification is most difficult (at the level of the ovoids) the plastic tubes did not provide useful information to visualise the source channels. For that reason direct applicator reconstruction on T2-weighted MR images was found to be not reliable. Applicator reconstruction is performed using two orthogonal digital X-ray images (gantry 0° and 90°). Radio-opaque dummy sources are used to identify and reconstruct the source positions.



Reconstruction

The applicator is reconstructed on x-rays by defining the source path using the radio-opaque markers. The first reconstruction point is positioned in the middle of the first marker, which corresponds with the first source position. The 'offset' value in BPS is 0.0 mm.

The x-ray based plan is registered to the transversal MR image set using manually defined matching points: the tip of the three catheters and an additional point at the top of the bladder balloon.

On x-ray images of a patient the matching points are placed at the tip of the dummy markers, as the outer applicator contours are not visible. On the MR images however, we aim to place the matching points at the physical tip of the catheters, as we cannot see the marker tips. That means that theoretically there is a systematic difference in the location of the matching points of 1 mm for the ovoidal catheters and 2 mm for the intra-uterine tube.

The systematic difference is however often smaller. The MR matching point can only be placed in the middle of the slice. However, this location does not always represent the real applicator Given tip. the uncertainty of the 4 mm slice thickness it is likely that the image shows the tube at a level lower than the real tip, close to the marker tip. An example of this is shown in case 2 of the figure. So, instead of trying to correct for this systematic error (e.g. by defining additional applicator offsets in the



reconstruction procedure), we decided to accept it.



The matching accuracy is qualitatively verified in EVAL 3.1 by checking the position of the projected sources in the transversal images, as well as in a sagittally reconstructed image (see figure below). If this is not okay, the position of the matching points on the MRI is moved slightly and the matching procedure is repeated until the sources project onto the intra-uterine tube void .

B. TPS: Nucletron-Oncentra

to be added later

Procedure at UMC Utrecht

Imaging and contrast in applicator

MR scans with the applicator in situ are made using a 1.5 T MRI scanner (Gyroscan NT Intera; Philips Medical Systems, Best, The Netherlands). The procedure consists of 4 MR sequences: a T2-weighted transversal (30 slices, 4.5 mm slice thickness), a T2-weighted coronal (26 slices, 4.5 mm slice thickness), a T2-weighted sagittal (26 slices, 4.5 mm slice thickness) Turbo Spin Echo (TSE) scan and a balanced Steady State Free Precession (bSSFP) (100 slices, slice thickness 1 or 1.5 mm) scan. All scans are made at the Radiology department within one session, with fixed origin, typically within a total acquisition time of about 20 minutes.

If possible (in one of our applicator sets with enlarged entrance of the applicator channels) MR dummy catheters are placed (Nucletron). For the other applicator sets no dummies are used.

We use In house developed software package VolumeTool for the contouring of target and organs at risk (OAR). Delineation is performed on the transversal T2-weighted TSE images, using the visual aid of the sagittal and coronal T2-weighted TSE images. The contours are saved with respect to the transversal bSSFP slices.

After each application also two orthogonal X-ray images are made.

Reconstruction

In Plato BPS we use the following reconstruction procedure: the bSSFP dataset is imported into Plato BPS of which the insight module enables multi-planar reconstructions in arbitrary planes. The applicator appears as a black signal void in the MR datasets. For each of the three separate parts of the applicator, that is right ovoid, left ovoid and tandem, a suitable set of axes is chosen, in such a way that for the ovoids the axes align with the major axes of the geometrical structure. Based on the knowledge of the geometrical dimensions and the track of the source channel, it is then possible to reconstruct the channel.

We have made geometrical correct templates of the ovoids, based on X-ray images, for each of our applicator sets with standard dummy catheter in situ (Standard CT/MR Applicator Set, Fletcher CT/MR Applicator Set, Utrecht CT/MR Applicator Set)



By this procedure, the black void with rather blurred edges due to partial volume effects is compared with the template of the appropriate structure. In practice this is done by first adjusting the scaling on the screen, and using a transparency of the template of the ovoid overlaid on the screen. The channel is reconstructed from the tip, along the track. The offset in BPS is minus the distance from tip to first dwell position. For the MR data sets with MR dummy catheters, it is easier to reconstruct the channel, although the template method is still used for marking the tip, and thus, using the offset, determine the first dwell position.

After reconstruction of the three parts of the applicator, the tracks of the channels with all source dwell positions active are always checked on the axial slices, with emphasis on the tip of the tandem. If necessary, corrections are made.

Procedure in Valencia

Imaging and contrast in applicator

For delineation of the organs of interest the established sequences are: longitudinal acquisition to cover the applicator tip and an axial acquisition covering the whole implant plus anatomical volumes of interest. Slice thickness is 4 mm without a gap between the slices. Both acquisitions are performed in T2 turbo spin echo sequence with FOV 27 cm without fat suppression. SNR 100% and NEX 2.8 channel body lower coil is used. Echo Time (TE) and Repetition Time (TR) are: for longitudinal acquisition TE = 100 and TR = 6020 and for axial acquisition TE = 100 and TR = 5000. Typical longitudinal and axial total acquisition times are 6-7 min for each. The used MRI machine has field strength of 1.5 Tesla.

The new version CT-MR compatible Nucletron tandem plus colpostats are used where the entrance diameter has been increased up to 2.5 mm (this modification does not affect to the region of applicator inside the patient). Dummy catheters are 6F (external diameter 2.3 mm) blind end plastic catheters filled with saline water (0.9% NaCl). A small proportion of antiseptic dermatologic (BetadineR) is included for colour purposes to check bubbles. These are clearly seen in both axial and longitudinal acquisitions.





Reconstruction

To avoid the uncertainty introduced by the slice thickness, a procedure utilizing both axial and longitudinal image acquisitions is used. In the longitudinal set, the position of the first axial MR slice that defines the catheter can easily be seen. With a ruler tool function the distance from this first slice centre to the deeper fluid position can be easily obtained.



The reconstruction procedure is as follows:

- a) The three catheters (filled with saline solution) are fully introduced in the tandem plus colpostats; these catheters must touch the deepest inner tunnel position.
- b) A set of longitudinal slices covering the 3 catheter's tips are acquired. Axial slices that encompass all the volume of interest are acquired.

- c) The deepest fluid position is obtained with the ruler from the first axial slice that defines a catheter.
- d) Because the catheter has a 2 mm plastic tip and the DID is at 5 mm from the end of the applicator tunnel, the required offset is obtained for each catheter and introduced in PLATO BPS where a reconstruction based on pure axial slices is performed.



Nucletron ring applicator

Daniel Berger and Christian Kirisits (Medical University of Vienna)

Geometry of Applicator

Position of X-ray markers and source channel relative to outer surface of applicator

As depicted in figure 1, the distance from the source channel (center plane of ring) to the upper surface of the ring (cranial direction) is 6 mm while the entire ring thickness is 14.5mm. Therefore point A should be located 26 mm above the source channel center plane for the ring. For the Tandem the first source position is defined 7.5 mm below the tip of the tandem. When tandem and ring is prober fixed together the geometrical distance between first tandem source position and level of ring center plan should be equal to the nominal tandem length (20 mm, 40 mm, 60 mm or 80 mm) minus 2 mm, which results in 18 mm, 38 mm, 58 mm or 78 mm according to the used tandem length.

When using additional needles, the distance between first source position and needle tip must be know (should be in the range of 5 mm - 10 mm) depending on the needle type. This distance can be measured with autoradiograph QA procedures individually by each institution.

Figure 1: Dimensions of the tandem-ring applicator



As can be read out from the small table (right upper corner of figure 1 depicting nominal and outer diameter of the ring) the lateral source – surface distance should be ~ 6 mm.

Rotation of the ring (first source position of the ring)

Independent from the used method to visualize and finally reconstruct the source path of the ring (X-ray markers, CT-scans or MR-line markers demonstrated as an example in figure 2) the distance of the first source position of the ring an outer (or other reliable landmark) must be known and verified. In this example the angle (Figure 2a) of the first ring source position to the aligned connection bar (Figure 2c and 2d) is defined as following

Ring size 26mm	->	~28°
Ring size 30mm	->	~34°
Ring size 34mm	->	~35°

It has to be mentioned, that all given dimensions taken from positions based on X-ray markers may differ when taking into account the real source position due to source positioning and applicator manufacturing uncertainties. Nevertheless, this information has to be recorded during commissioning (autoradiography QA acceptance tests) of the applicators by the medical physicist. Please not that all determined positions during QA should be tolerated within 2 mm.

Figure2: MRI of the Vienna ring applicator with MR-line dummy marker in place to depict the source channel



Reconstruction Procedure

When using radiographs, CT or different specialized MR sequences to reconstruct the applicator, a registration to the final "planning" MR image (T2 weighted MRI) data set must be performed. The registrations between image modalities can be checked using the knowledge of applicator geometry indicated above. If the "accurate" reconstructed applicator appears prober on the planning MR image data set, the registration can be used for planning.

When using the MR directly for planning, the same criteria are valid.

Further detail of proposed reconstruction methods are include in the listed literature.

! Beware of using the "direct reconstruction" of the source path based on X-ray dummy wire or MR line marker only !

Double-check of the reconstruction

There is always an additional quality check required.

- 1) Check the plausibility of the 1st source position (Figure 2)
- 2) Try to use "library plans" when reconstructing a ring applicator [4]
- 3) Perform autoradiography to check if the source path of "library plans/geometries" are correct stored/reconstructed in the TPS (Figure 3)

Figure3: Autoradiography of dwell positions (in red 1,12,23,34)



Literature:

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Mould applicator

Isabelle Dumas (Institut Gustave-Roussy)

Geometry of applicator

Vaginal mould description

The mould is made in polymerizable resin named "Palapress" (Fig 1) based on the vaginal impression. It is MRI compatible.

Mould advantages consist of a precise tumour extension evaluation, especially within the vagina, and a good accuracy in the placement of plastic catheters for radioactive sources as regards to the tumour.

Mould usually contains two vaginal tubes fixed to the wall mould and one uterine tube.



Fig 1 : Vaginal mould applicator

Reconstruction procedure

Procedure at Institut Gustave Roussy (Nucletron PlatoBPS V14.3.5. TPS))

- MRI imaging

MRI-compatible dummy sources designed at our institution are inserted into the catheters to visualize the intrauterine and vaginal positions of the sources (Fig 2 and Fig 3). These dummy sources have a 2 mm diameter and are filled with glycerine. Fast spin-echo T2-weighted images (TE 120s, TR 4100s) are acquired on a General Electric Signa Excite 1.5T MRI machine. Axial and sagittal images are acquired with 3-mm slice thickness, no interslice gap, and a matrix size of 256×224 .



Fig 2 : Example of sagittal image with glycerine catheters



Fig 3 : Example of transverse image with glycerine catheters

- Reconstruction

Sources paths are directly digitized in each axial MRI slice.

Orthogonal X-ray films are realised using X-ray dummy sources (Fig 4) to check the applicator MRI reconstruction. Sources coordinates and specific points including ICRU bladder and rectal points, one bladder point 1.5 cm above the ICRU bladder point, points A and A' (left and right) are digitized on X-ray films (Fig 5) and reported on MRI images.



Fig 4 :Example of X-ray film



Fig 5 : Sources coordinates and patient points digitized in X-ray films

The same axis origin and plans are chosen on X-ray films and MRI to compare the applicator reconstruction. The first source position coordinates for the film is reported on the MRI (blue point in Fig 6) and compared to the first source positions directly digitized on the MRI images.



Fig 6 : Reconstruction applicator in MRI modality with first source positions of the film in different catheters (blue points) reported on MRI study

In the same way, specific points digitized on X-ray films are reported on MRI images.

The applicator reconstruction can be checked in different MPR plans (Fig 7 and 8)



Fig 7 : projection of the source path on MPR



Fig 8 : Projection on MPR of the source path and vagina structure delineated

ICRU bladder point reported on MRI also allow checking the reconstruction by comparing the point position and the bladder balloon (Fig 9)



Fig 9 : Applicator reconstruction check

Titanium needles

Kari Tanderup (Aarhus University Hospital) Robert Hudej (Institute of Oncology Ljubljana)

Geometry of applicator

Position of x-ray markers and source channel relative to outer surface of applicator

An example of a titanium needle (Akrostak) geometry is shown below for a blunt needle used in Aarhus. The thickness of the needle tip is in this case 3.7 mm. In contrast to this, the blunt plastic needles used at Institute of Oncology Ljubljana have a needle tip thickness of less than 1mm. We do not have all different needle geometries tabulated, and each institution needs to assess individually the thickness of their needle tip.



Reconstruction procedure

<u>Procedure at Aarhus University Hospital (Brachyvision TPS) – also described in Haack et al,</u> <u>"Applicator reconstruction in MRI 3D image based dose planning of brachytherapy for cervical cancer", Radiother Oncol,2009 in press</u>

Imaging

Paratransversal T1 (3mm slice spacing) and T2 (5mm slice spacing) are obtained. The sequences are registered on scanner coordinates when possible. However, if internal movement has happened in between the T1 and T2 sequences a manual registration on the applicator is performed. Dummy catheters containing CuSO4 do not produce any visible signal due to susceptibility artifacts of titanium. In case of free needles which are not perpendicular to the slice orientation, it is sometimes difficult to discriminate the end of the needles. Therefore, we perform additional CT when we

consider this to be necessary. CT is then matched to T2 MRI. Contouring and dose planning is performed in T2 weighted images, and reconstruction is aided by visualisation on CT.

Reconstruction

For titanium needles, there are susceptibility artifacts around the needle – especially in the tip region. In coronally reconstructed images these are bright regions to the left and right of the needle - figure (b) below.

For reconstruction, needles are visualized in the sagital and coronal reconstructions. Lateral and anterior-posterior positioning is determined from the signal void. The position of the tip of the needles is identified from the titanium artifacts (figure 3.b, c), and the end of the source path is defined 3.7mm (for Aarhus needle) below the tip according to the thickness of the needle tip.



Blunt plastic needles: procedure at Institute of Oncology Ljubljana (Brachyvision TPS)

Imaging

Paratransverse T2 fast-spin echo (FSE) sequence (0.6x0.6 mm pixel size, 3.9 mm slice spacing) and T2 fast-recovery fast-spin echo (FRFSE) sequence (1 mm isotropic voxels) are obtained. The sequences are registered on scanner coordinates and checked for any applicator shifts, which may occur between the two sequences. If the shift is equal or larger than 1 mm, manual registration correction is performed.

Reconstruction

The position of the needle channel end is reconstructed at the tip of the needle, as it is visible on the FRFSE image (plastic wall thickness beyond the active channel end is ≤ 1 mm, i.e. smaller than the image resolution and the afterloader accuracy, therefore, it doesn't have to be taken into account).