Original article

Comparison and verification of the reconstruction method of the catheters for interstitial brachytherapy

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Abstract

Purpose: 1. Comparison and verification of accuracy of the implant reconstruction method based on images from IBU and CT. 2. Estimation of influence of the implant reconstruction method on dose disposition in selected reference points.

Material and methods: Paraffin-wax phantom with three catheters, central marker and control point were prepared. IBU unit were used for obtaining two series of images for reconstruction. The Earth magnetic field correction algorithm was used to correct S-shape distortions of the images. CT images (1 mm slice) were prepared. In the treatment planning system positions of 15 catheter points (MP, measure points), control point (CP) and central marker (CM) were reconstructed for each series of images. Distances between 15 catheter points and control point, and between catheter points and central marker were calculated.

Results: There were no statistically significant differences observed for IBU and CT based reconstructions for all orientations of the phantom ($p > 0.05$, U-Mann Whitney Test). There were no statistically significant differences observed between reconstruction based on IBU images with and without Earth magnetic field correction algorithm for phantom located perpendicular to the IBU table ($p > 0.05$, Wilcoxon Test). Statistically significant differences were observed only for images set with long axis of the phantom located parallel to the table ($p < 0.05$, Wilcoxon Test). There were no statistically significant differences observed for values doses in reference points for reconstruction based on IBU images and CT for all orientations of the phantom.

Conclusions: 1. Obtained results showed that IBU (radiographs based) reconstruction of the catheter placement is the reliable and accurate method for interstitial implants when reconstruction based on CT "catheter tracking" is not possible or not necessary. 2. The Earth magnetic field correction algorithm should be always use to correct S-shape distortions; reconstruction will be more accurate in particular orientations of image intensifier of the imaging unit.

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Key words: interstitial brachytherapy, catheter reconstruction, treatment planning.

Purpose

Accuracy and reproducibility of catheter localization and reconstruction of the implant geometry is one of the most important quality factor for treatment planning in interstitial brachytherapy. For relatively low energy and high dose rate gradients observed for HDR brachytherapy, consequences of even small reconstruction errors could be relevant for the dose distribution. For conformal 3D brachytherapy the most common method of reconstruction of the implant geometry is "catheter tracking" based on CT images [1, 2]. In case of applying CT for localization of applicators, the use of digital radiographs is not possible or sometimes not necessary. Positioning of the patient and implant geometry are relative to the geometry of the imaging device and may well be important for accuracy of the implant reconstruction. Catheters might overlap each other and some of them could not be visible or difficult to distinguish. The earth magnetic field is the reason for S-shape deformations of images and possible addition of fraction to the overall reconstruction accuracy and reproducibility [3-7].

The aim of this study is to estimate the accuracy of the catheter geometry reconstruction for interstitial brachytherapy in two different imaging methods and the evaluation of possible inaccuracies of dose distribution calculation.

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Material and methods

Phantom description

For the evaluation of the accuracy of the implant geometry reconstruction authors prepared the paraffin-wax phantom showed in Fig. 1. Three plastic interstitial catheters were vertically adjusted to the long axis of the paraffin-wax rectangular prism in equilateral triangle configuration. Similarly, standard steel needles used for interstitial brachytherapy were applied as well as metal coin in the lower part. The intention for placing metal structures inside the volume of the phantom was to generate the imaging artifacts when CT scans were used for reconstruction. In the upper part, a crosshair marker made of fine steel wire was positioned for repeatable phantom placement during imaging. Small point marker was also located inside as the reference point for distance measurements (PM).

Image acquisition and geometry reconstruction

The Integrated Brachytherapy Unit (IBU – Nucletron, L+C arm) was used for acquisition of plain radiographs and for reconstruction of the geometry the Somatom Sensation Open (Siemens) was applied in order to obtain the CT images [3, 8-10]. For the treatment planning and reconstruction of the geometry, Plato v 14.3.7 system was used. In this method two plain images are necessary to perform three dimensional reconstruction of geometry of the application [2, 11]. Two sets of images were prepared; first set for images without S-shape distortion correction and second for images with S-shape correction algorithm. Each set consisted of two pairs of images. One pair with long axis of the phantom parallel (and catheters perpendicular) to the long axis of the IBU table and second one with long axis of the phantom perpendicular (and catheters parallel) to the table. Each single pair of images included images with L-arm angles 45 deg and 325 deg and C-arm angle, always 270 deg.

CT images of 1mm scan thickness were prepared in similar way – with catheters perpendicular and parallel to the long axis of the table. After the importation of all pairs of plain radiographs to the treatment planning system, the standard reconstruction of three dimensional geometry was performed. Five points placed inside of each catheters were marked as measure points (MP), MP1-MP5 in the catheter C1, MP6-MP10 in the catheter C2, and MP11-MP15 into the catheter C3. The location of measuring points was based on clearly visible CT-markers that were applied during each image acquisition (IBU and CT). Control point (CP) position was determined with the use of a marker (Fig. 1) placed inside the phantom (Fig. 2). Whole procedure of points reconstruction was repeated for each of two image sets obtained from CT scanner. After reconstruction procedures, a spreadsheet was prepared for calculation of controlled distances. For each set of images – distances from each measure point (MP) to the center of the coordinate system (center of the crosshair) were calculated, and also distances from each measure point (MP) to control point (CP). Calculations of the distances were repeated for each modality of the imaging – IBU with and without S-distortion correction as well as for CT images respectively. Geometrical dependencies between points for two orientations of the phantom are presented in Fig. 2.

For statistical evaluation of the obtained distances (calculated from IBU images for two different phantom orientation and for corrected and uncorrected S-shape distortions) the Wilcoxon Matched Pair Test for dependent samples at α = 0.05 was used [12-15]. For comparison of the results from IBU images vs. CT images intended for two orientations of the phantom respectively the Mann-Whitney U Test for independent samples at α = 0.05 was applied [12-15]. The evaluation of the influence of reconstruction method in treatment plan dose distribution, based on each image set was arranged. Active length was established at 4 cm (9 positions with 5 mm step source) in all three reconstructed catheters. Dose of 10 Gy was prescribed at source position – as well as catheter – and was depended on dose points located at 7 mm distance from the axis of each catheter toward the outside. Nine dose control points (DCP) which positions were based only on central point position (crosshair) were used for determining the dose distribution in the implant area. All nine points were located at the plane perpendicular to the implant in the middle of the active length. Three points DCP 1-3 were located at potentially high dose area with another three DCP4, DCP8, DCP9 in the middle of the distance between

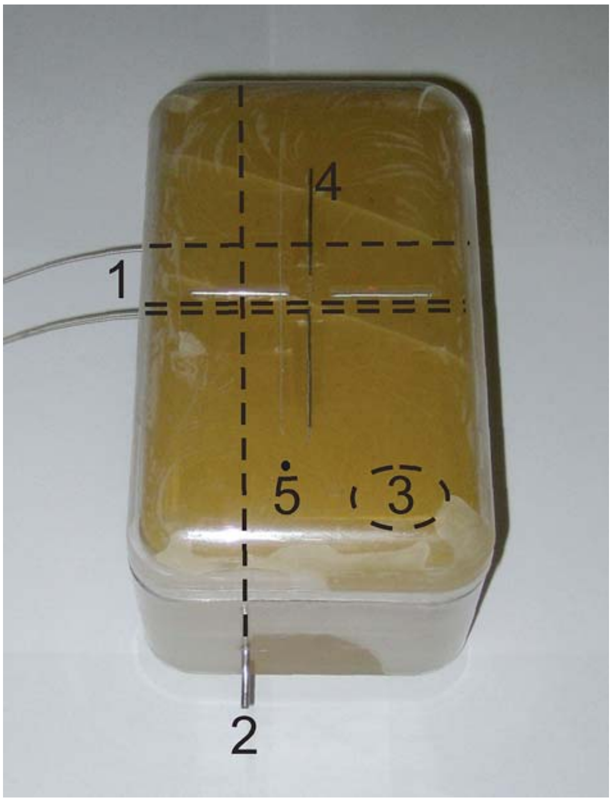

Fig. 1. Paraffin-wax phantom used for evaluation of accuracy of the implant geometry reconstruction: 1 – three plastic catheters, 2 – steel needle, 3 – coin, 4 – crosshair marker, center of the coordinates system (CC), 5 – control point marker (CP)

catheters, and the last DCP 5-7 at 5 mm distance from the ideal (hypothetic) axis of the catheters. Geometry relations for the prepared treatment plans are shown in Fig. 3. Evaluation of obtained doses for IBU images was completed with the help of Wilcoxon Matched Pair Test for dependent samples at $\alpha = 0.05$. For comparison of the doses from treatment plans based on plain radiographs (IBU) and CT-images, the Mann-Whitney U Test for independent samples at $\alpha = 0.05$ was applied.

Results

IBU images based on reconstruction of the catheters geometry and coordinated measure points (MP) allowed

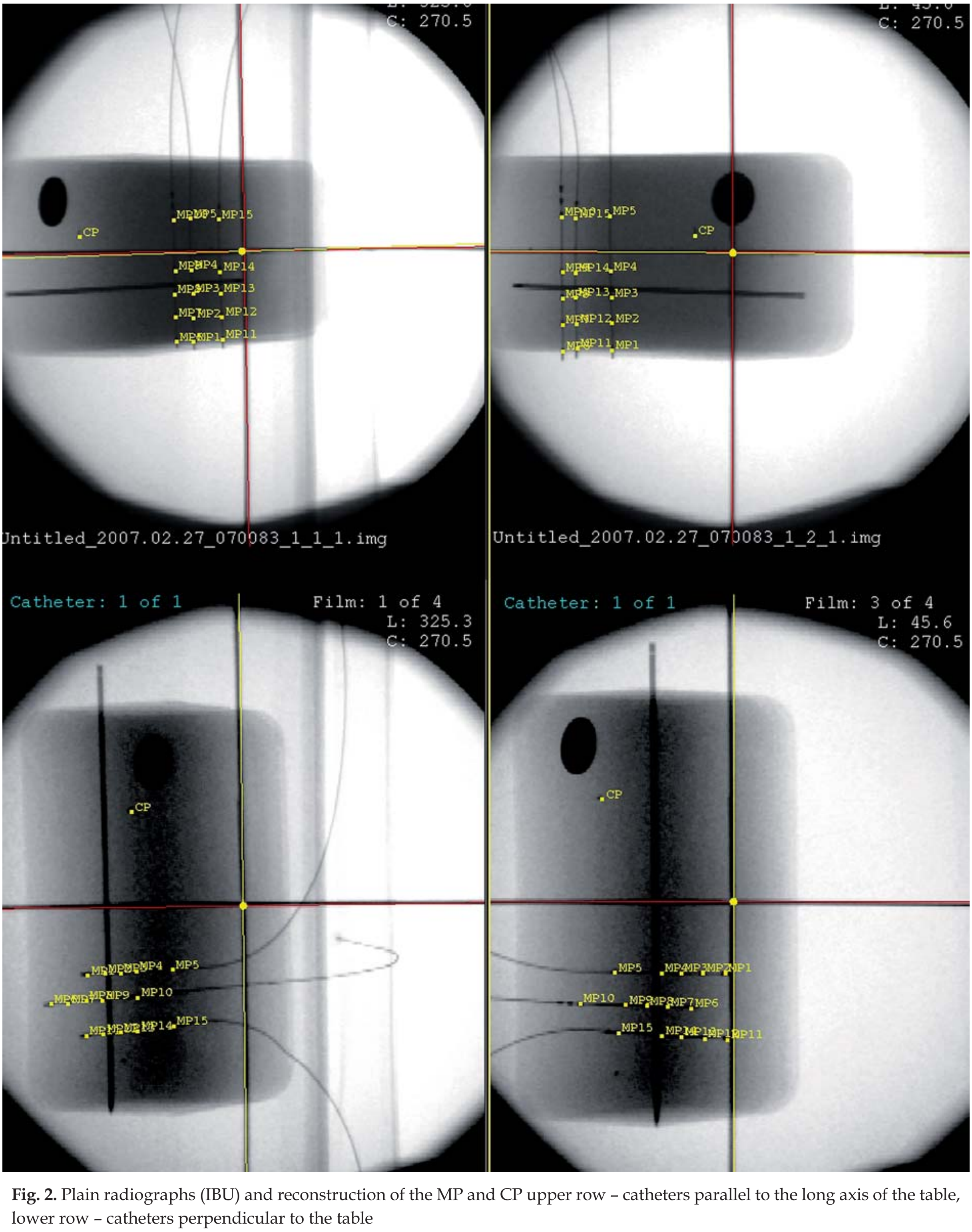

Fig. 2. Plain radiographs (IBU) and reconstruction of the MP and CP upper row – catheters parallel to the long axis of the table, lower row – catheters perpendicular to the table

to calculate the distances from measure points M1 to M15 to the center of the coordinative system (crosshair – CC) called MPCC value, and from points M1 to M15 to control point (CP) called MPCP value. Obtained distances based on reconstructions (MPCC and MPCP values) were compared with images with (IBU_SC) and without (IBU) S-shape correction algorithm, applied to the radiographs. Distances were evaluated for catheters perpendicular and parallel to the long axis of IBU table respectively. Wilcoxon Matched Pair Test p-values is presented in Table 1.

Statistically significant differences were observed only for reconstruction of the catheters geometry based on images with catheters perpendicular to the long axis of the IBU table (the phantom was oriented parallel to the long axis to IBU table).

Distances from measure points (MP1-MP15) to CP and CC points were also calculated for CT images based on the reconstruction of the catheters geometry. Obtained distances were compared with corresponding values from CT images based on reconstruction for both orientations of the phantom and from IBU images based on reconstruction with and without S-shape correction algorithm applied. Mann-Whitney U Test p-values for MPCC and MPCP distances is presented in Table 2.

There were no statistically significant differences observed.

Treatment plans based on IBU geometry reconstruction were prepared for both orientations of the phantom (IBU, IBUP) and for radiographs without and with S-shape correction algorithm (IBU_SC, IBUP_SC). Dose values from dose control points (DCP1-DCP9) were compared for prepared plans respectively. Wilcoxon Matched Pair Test p-values is presented in Table 3.

There were no statistically significant differences observed.

For treatment plans based on CT reconstruction dose values from dose control points (DCP1-DCP9) were calculated and compared with corresponding values from IBU treatment plans for both orientations of the phantom (CT vs. IBU, CT vs. IBU_SC for parallel and CTP vs. IBUP, CTP vs. IBUP_SC for perpendicular orientation). Dose values from plans based on corrected and uncorrected

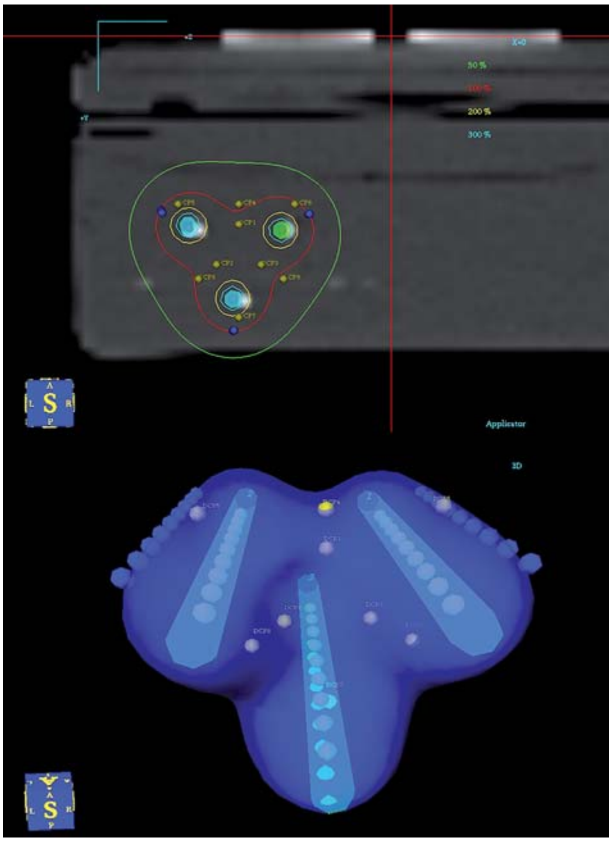

Fig. 3. Example of two (upper part) and three dimensional dose distribution (lower part) for treatment plans prepared. Geometrical dependencies between reconstructed catheters and dose control points (DCP) are shown

Table 1. Wilcoxon Matched Pair Test p-values for MPCC evaluation (distance between measure point and center of the coordinate system) and MPCP evaluation (distance between measure point and control point) distances. Column 2 contains p-values for comparison of the results from IBU images with vs. without S-distortion correction (the phantom was oriented parallel to the long axis of the IBU table). Column 3 contains p-values for comparison of the results from IBU images with vs. without S-distortion correction (the phantom was oriented perpendicular to the long axis of the IBU table)

Wilcoxon Matched Pair Test		
	IBU_SC vs. IBU	IBUP_SC vs. IBUP
MPCC (mm)	0.010	0.800
MPCP (mm)	0.011	0.394

Table 2. Mann-Whitney U Test p-values for MPCC and MPCP distances. Column 2 and 3 – p-values for comparison of the results from IBU images with and without S-distortion correction vs. CT images respectively (the phantom was oriented parallel to the long axis to the IBU table). Column 4 and 5 contains – p-values for comparison of the results from IBU images with and without S-distortion correction vs. CT images (the phantom was oriented perpendicular to the long axis to the IBU table)

Mann-Whitney U Test				
	IBU_SC vs. CT	IBU vs. CT	IBUP_SC vs. CTP	IBUP vs. CTP
MPCC (mm)	0.838	0.956	0.696	0.696
MPCP (mm)	0.935	0.867	0.713	0.744

Table 3. Wilcoxon Matched Pair Test p-values for comparison of the doses from treatment plans based on plain radiographs (IBU) with and without S-distortion correction (the phantom was oriented parallel and perpendicular to the long axis to the IBU table respectively)

Wilcoxon Matched Pair Test	p-value
IBU vs. IBU_SC	0.859
IBUP vs. IBUP_SC	0.314

radiographs were also evaluated. Mann-Whitney U Test p-values is presented in Table 4.

There were no statistically significant differences observed.

Discussion

For the verification of the reconstruction of the catheters geometry for interstitial brachytherapy the paraffin-wax phantom was used. Two pairs of images for IBU and CT techniques were prepared. For the reconstruction of the catheters IBU images were applied when the phantom was situated parallel to the long axis of the IBU table, the applicators set was located in perpendicular orientation. The specificity of the catheters localization and reconstruction procedure in Plato system creates uncomplicated execution, whenever images of reconstructed catheters are projected as vertical lines or placed in some angles to the axis. Images where catheters are projected parallel to the axis and horizontal, causes reconstruction of the geometry that could be encumber by human errors. There were statistically significant differences observed for reconstruction of the applicators geometry based on images with catheters placed perpendicular to the long axis of IBU table for IBU images with and without S-distortion correction algorithm. For the reconstruction of the applicators of IBU images with the phantom placed perpendicular to the long axis of IBU table, the catheters set was projected parallel to the long axis of the table. Such set guarantees precisely and more intuitive reconstruction of the geometry of the catheters. There is a reduced amount of possibility of adding an effect of human depended errors to overall precision and repeatability of the catheter reconstruction. There were no statistically important dissimilarities observed for this sets of images. S-distortion correction algorithm for IBU images could be potentially important for reconstructions of longer applicators. Such application is compulsory whenever the amount of distortions depends on geometry of the installation of imaging device. The corresponding distances values from CT-based reconstruction were also compared (for both orientations of the phantom) with IBU images based on the reconstruction with and without S-distortion correction algorithm. However, no statistically significant differences were observed. For less complicated applications or in case when the usage of CT equipment is not possible, the implant reconstruction method based on IBU images can get quite reliable and repeatable effects. Nevertheless, it is important to consider two-dimensional images from IBU that allows to gather information only about the implant geometry (possible source steep positions) and not about the tissue geometry and density. The paraffin-wax phantom enables to perform verification of the dose values obtained in Plato system. Nine dose points depends only on localization of the central point position and they were used to determine the dose distribution in the implant area. There were no major dissimilarities observed for both reconstruction method – IBU and CT. Low radiation energy causes the occurrence of high dose gradients of exterior and interior of the implant. Even small miscalculations in the reconstruction with combination of high dose rate (HDR) could cause clinically important differences of the dose distribution.

Table 4. Mann-Whitney U Test p-values for comparison of the doses from treatment plans based on plain radiographs (IBU) with and without S-distortion correction and CT-images (the phantom was located parallel and perpendicular to the long axis to the IBU table respectively)

Mann-Whitney U Test	p-value
CTP vs. IBUP	0.931
CTP vs. IBUP_SC	0.931
CT vs. IBU	0.731
CT vs. IBU_SC	0.931

Conclusions

1. Obtained results showed that IBU (radiographs based) reconstruction of the catheter placement is a reliable and accurate method of interstitial implants whenever reconstruction – based CT "catheter tracking" is not possible or not necessary.
2. The Earth magnetic field correction algorithm should always be applied in order to correct S-shape distortions; therefore, the reconstruction would be more precise in particular orientations of image intensifier of the imaging unit.

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