MR vezérelt magas dózisteljesítményű prostata brachytherápia:

metodikai, dozimetriai, klinikai aspektusok

Doktori (PhD) Értekezés

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CT és MR vezérelt diagnosztikai és terápiás intervencionális beavatkozások fejlesztése.

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– A biokémiai kontrollra, késői mellékhatásokra, életminőségre gyakorolt hatás megítéléséhez nagyobb betegszám, hosszabb követési idő szükséges.

3. Az MR vezérelt prostata HDR-BT a TRUH vezérelt beavatkozások életképes alternatívája lehet, amennyiben intézeti szinten a megnövekedett idő-, munkaerő-, hely- és anyagköltség megengedhető, felvállalható. Szelektált esetekben az MR nyújtotta többletinformáció közvetlen felhasználása, integrálása az intervencióban és besugárzás tervezésben egyértelmű előnyt jelenthet.

1. Introduction

Prostate cancer is the most common male malignant disease in the Western world. In Hungary, 2839 new cases were registered in 2001, while in 2004 more than 4000 new cases of prostate cancer were diagnosed. However, the mortality rate has not changed. Due to early PSA screening tests the majority of the patients with prostate cancer are diagnosed with potentially curable disease, which explains the stable mortality rate. Thus, the primary goal of the development of minimally invasive prostate interventions is to not only achieve better tumor control, but preserve quality of life. Currently, the two most accepted methods for treatment of localized prostate cancer are radical prostatectomy and radiation therapy. Although both of these approaches are associated with a good chance of a cure, they are also associated with a substantial risk of morbidity, including incontinence, rectal toxicity, and erectile dysfunction. Due to these conflicting factors, there have been increased efforts to develop minimally invasive interventions like brachytherapy (BT) that can be used to target cancerous tissue while reducing morbidity and treatment duration.

Existing evidences show that biochemical control rates are improved if the delivered dose to the prostate gland is increased. Besides modern external-beam radiotherapy (EBRT) techniques like three dimensional conformal radiotherapy or intensity-mod-

ulated radiotherapy, BT could be a feasible method for achieving local dose escalation with stable or reduced acute and late morbidity. The essence of interstitial BT is to place radioactive sources directly into the prostate gland through transperineally inserted catheters. Based on the inverse square law, either form of BT could achieve a high radiation dose in the close vicinity of the sources that being the implanted prostate, with a rapid dose decline beyond the gland preserving surrounding normal tissues.

The gold standard technique for guidance of BT is transrectal ultrasound (TRUS) due to the ease of use, low costs and fast real-time 3D image acquisition connected with its new developments. Given that accuracy in BT is largely dependent on the planning image quality, the rationale is strong for using magnetic resonance imaging (MRI) for the treatment planning of BT. The ability to use high quality MRI for treatment planning allows a precise definition of target and critical structures. Additional refinements in targeting will now be possible by adapting functional and biologic imaging. By localizing the intraprostatic ±extraprostatic tumor MRI may help to define areas within the target that may benefit from local dose escalation and predict better outcome. MRI is able to visualize the neuro-vascular bundles (NVBs) and penile bulb directly during implantation. This provides an opportunity to minimize both needle traumatic and radiation injury during BT, resulting in lower morbidity.

Considering MR-guided prostate BT, three general approaches are actively under investigation, including diagnostic MR image fusion with the intraoperative ultrasound images, the use of low-field "open" MRI scanners (0.2–0.5 Tesla (T)) and the direct use of high-field closed bore MRI systems (1.5–3T).

In our Institution an open configuration MRI scanner is available for MR-guided interventions. In 2006 we have initiated a three phases – gel phantom, cadaver and healthy – canine study to develop a methodology for MR-guided high-dose-rate (HDR) prostate BT. The excellent preliminary results facilitated us to in-

troduce this method into the clinical practice as a boost treatment for patients with intermediate- or high-risk prostate cancer.

2. OBJECTIVES

1. To develop and test the methodology of MR-guided prostate high-dose-rate (HDR) BT:
   - On gel- and *in vitro* animal phantoms
   - On *in vivo* canine models

2. To introduce MR-guided HDR-AL BT into the clinical practice with the description and interpretation of the following cornerstones:
   - Methodology
   - Needle placement accuracy
   - Image quality
   - Catheter induced organ motion
   - Dosimetric analysis
   - Intervention tolerance, acute side effects
   - Working time
   - Biochemical control, late side effects, quality of life analysis-only with preliminary results due to the short follow up period and low number of patients.

3. METHODS AND MATERIALS

3.1. Pre-clinical studies

The methodology has been developed on gel phantoms, *in vitro* and *in vivo* animal studies. The interventions were performed in an open-configuration 0.35 T MRI scanner under epidural anaesthesia, at the beginning in lateral decubitus position thereafter in lithotomy position. The details of the whole methodology in-

cluding positioning, imaging, MR compatible devices, template reconstruction, trajectory planning, catheter placement, contouring have been described in the PhD thesis and in our previous publications.

3.2. Patient and tumor characteristics

Between October 2007 and August 2009 altogether 39 MR-guided prostate HDR-BT procedures have been successfully performed on 34 patients. The mean age was 65.7 years (range: 53–77), the mean initial PSA was 16 ng/ml (3.9–57.4), while the median Gleason score was 6 (2–8). The majority of the patients were diagnosed with intermediate- and high-risk prostate cancer. 29 patients were treated with a single fraction preceded or followed by EBRT. The remaining 5 patients received two implant sessions interposing EBRT. Twelve patients had visible extraprostatic tumor extension on MRI.

3.3. Treatment planning

In the first 6 procedures only dose-point optimization (DPO) (Theraplan Plus version 3.8; Anatomy Modelling; MDS Nordion; Quebec; Canada) was used, while in the remaining 33 interventions, anatomy-based inverse planning optimization (IPO) was performed with or without graphical or dwell time optimisation (Brachyvision version 8.1; Varian Medical Systems, Inc; Palo Alto; USA).

3.4. Dosimetric analysis

Volume and dose parameters for target (in percent):

V100, V150, V200: the volume of the planning target volume (PTV) receiving 90%, 100%, 150%, and 200% of the prescribed dose (PD).

D90: the minimum dose delivered to 90% of the PTV.

Volumetric indices:

DNR = V150 /V100, dose nonuniformity ratio,
where V100 and V150 are the absolute volumes in cm^3 irradiated by 100% and 150% of the PD

DHI = (V100–V150)/V100, dose homogeneity index

COIN = $PTV_{ref}/V_{PTV} \times PTV_{ref}/V_{ref}$, conformal index,
where *Vref* is the volume irradiated by the PD, *Vref = V100*, *PTVref* is the absolute volume of the PTV irradiated by the PD.

Dose parameters of the OARs:

$D_{r0.1}$, D_{r1}, D_{r2}: Dose to volume of the most exposed 0.1, 1 and 2 cm^3 of the rectal wall (%)

$Du_{0.1}$,Du_1: Dose to volume of the most exposed 0.1 and 1 $cm^3$of the urethra (%)

D_u1: Dose to volume of the most exposed 1% of the urethra (%)

D_{rmax}: Maximal point dose of the rectal inner surface.

3.5. Assessment of side effects and quality of life

Acute toxicity was graded according to a modified Radiation Therapy Oncology Group scale recommended by De Meerleer Gert *et al.* Late side effects were graded according to the Common Terminology Criteria for Adverse Event Version 3. Analysis of quality of life and urinary function were assessed using the Expanded Prostate Cancer Index Composite and the International prostate symptom score.

4. Results

4.1. Gel phantom, *in vitro* studies

4.1.1. Needle Placement Accuracy

The mean±standard deviation (SD) of the coaxial needle insertions in gel phantom, pig kidney and cadaver canines were 1.0±0.4 mm, 1.1±0.6 mm and 1.9±1.1 mm,respectively.

4.2. In vivo canine study

4.2.1. Intervention tolerance

In general, the interventions were well tolerated. There were no serious intervention related adverse events (i.e. injury of the urethra, rectal and bladder wall, extensive bleeding), neither in the intra-operative nor in the post-operative period. All of the canines except the sacrificed one recovered within 2 days.

4.2.2. Image quality

Despite the fact that a 9-inch general purpose coil was used for pelvic imaging, our sequences allowed clear definition of the prostate, urethra, periprostatic tissues as well as the coaxial needles and brachytherapy catheters in all cases. On T2-weighted fast spin-echo (T2-FSE) images all plastic catheters were clearly visualized.

Plastic catheters were also well depicted on the T1-FSPGR images; however, the clear definition was limited in the close vicinity of the coaxial needles due to their large artifact effects.

4.2.3. Needle Placement Accuracy

Altogether, 37 coaxial metal needles and plastic catheters were inserted with an average target depth of 11 cm (range: 10.5–12.5 cm). Mean deviation of the needle displacements was 2.9 mm, with a median of 2.7 mm. The needle placement accuracy was modeled by the Rayleigh distribution with a sigma value of 2.3 mm.

4.2.3 Pathology Study

In one canine visual confirmation of eight needle placements was demonstrated. The distribution, depth and localization of the alcyan blue-stained catheter trajectories seen in the specimen slices clearly and favorably matches with the distribution, depth and localization of the plastic catheters as visualized on transverse T1-FSPGR sequences.

4.2.4. Coaxial needle induced prostate motion

During the implantations the position of the canine and the template-obturator system remained stable. Significant prostate motions were observed in the superior direction with a mean of 10.3 mm. The mean latero-lateral gland displacement was 2.3 mm. The majority of this motion was observed during the first 4 coaxial needle insertions.

4.2.5. Working time analysis

The overall time of the interventions in the MR unit, determined from the induction of anesthesia to extubation, gradually improved procedure by procedure. The total time of the final procedure, in which 12 catheters were implanted, was 2 hours. The

time needed for each step was the following: anesthesia – 15 min, setup and positioning – 15 min, initial imaging – 15 min, template registration and projection – 15 min, contouring, trajectory planning, needle insertion – 60 min.

4.3. Human procedures

4.3.1. Catheter placement accuracy

The insertion accuracy of the first 100 plastic catheters was modeled by the Rayleigh distribution with a sigma value of 2.3 mm. The calculated mean and median catheter placement error was 2.9 mm and 2.7 mm, ranging from 0.0 mm to 5.0 mm. 91% of the errors were less than 4.0mm.

4.3.2. Image quality

We have analyzed the image quality of the first twenty procedures. Image quality was assessed using a four point scoring scale (1: excellent, 2: fair, 3: diagnosis or accuracy in doubt due to poor quality, 4: inadequate quality) on each pre- and post implant T2-FSE images. The basis of the analysis was the following: visibility of the prostate at the base plane, mid-plane and apex; visibility of organs at risk; and visibility of the coaxial needle artifacts and plastic catheters. Except for the NVBs and the prostatic apex image quality was fair to excellent for all examined structures on both pre-implant and post-implant T2-FSE images. On pre-implant series the quality scores for NVBs and prostatic apex were 30–40% lower in the excellent category than for the other structures. This difference further increased after the implantation reaching a value of 45–55%, furthermore in 15–25% of the image series image quality was judged to be only acceptable.

4.3.3. Catheter induced prostate motion

The mean deviations and directions of the catheter induced prostate mortion were the followings: superior-inferior deviation: 13 mm (range: 4–22) exclusively in the superior direction; anterior-posterior deviation: 2.6 mm (range: 0–9.5) exclusively in the anterior direction; lateral-lateral deviation: 0.4 mm (range: 0–2.7) in both direction. Similar to the findings in the canine study the majority of the gland motions were observed during the first 4 needle insertions.

4.3.4. Dosimetric results

The average V100, for all patients was: 95.0±3.9%. Since there were a very limited number of procedures in the DPO group, and we have switched to IPO relatively early, we have only given a descriptive statistical analysis about the DPO group. The average V100, V150 and V200 for DPO and IPO were 89.0±4.0 vs. 96.1±2.8, 42.2±6.6% vs. 40.8±6.7% and 22.8±7.9% vs. 14.9±3.9%%, respectively. The average DHI, DNR and COIN were 52.5±9.5% vs. 56.8±7.0%, 39.7±6.7% vs. 33.5±4.2% and 69.2±7.0% vs. 67.6±5.9% for DPO and IPO, respectively. However, we compared the dosimetric values yielded in the lateral decubitus (IPO_{ld}) and in the lithotomy position (IPO_{li}) generated by IPO. We have found significantly ($p<0.05$) better results in each rectal parameter and in the values of V150, V200, DHI, $D_{u1}U_{IP}$ in favor of the IPO_{li} group.

4.3.5. Intervention tolerance

Generally the procedures were well tolerated. In the lateral decubitus position there was no necessary to interrupt the procedures due to shoulder or hip pain. There were no intervention related urethral or rectal injuries. No infections, fever or neuropathy were

observed. One patient experienced pressure injury to cutaneous pressure point on the right thigh due to inadequate support. On the second hospitalization day all patients voided spontaneously shortly after the removal of the urinary catheter. Seven patients (20.5%) presented hematuria which resolved within 48 hours in all cases. The hospitalization time was 3 days for all patients.

4.3.6. Acute side effects

Acute morbidity are demonstrated in *Table 1–2.*

Table 1. Symptom-related acute genitourinary side effects: baseline and radiotherapy induced side events

Symptoms	Baseline* (%)			Radiotherapy induced side effects (%)*								
				During RT			1 month			3 months		
	Gr.											
	0	1	2	0	1	2	0	1	2	0	1	2
Frequency	84	10	6	48	29	23	68	19	13	77	13	10
Nocturia	77	23	0	29	61	10	52	39	10	68	32	0
Dysuria	71	6	23	0	0	100	0	0	100	16	0	84
Urgency	52	32	16	16	26	58	39	26	32	52	26	23
Incontinency	97	3	0	97	3	0	97	3	0	97	3	0
Hematuria	100	0	0	77	23	0	100	0	0	100	0	0

Note: * data related to 31 patients

Table 2. Symptom-related acute gastrointestinal side effects: baseline and radiotherapy induced events

Symptoms	Baseline* (%)			Radiotherapy induced side effects (%)*								
				During RT			1 month			3 months		
	Gr.											
	0	1	2	0	1	2	0	1	2	0	1	2
Diarrhea	97	3	0	48	23	29	87	10	3	97	3	0
Frequency	94	6	0	55	16	29	84	13	3	90	10	0
Urgency	94	3	3	61	23	16	81	16	3	81	19	0
Anal pain	100	0	0	68	6	26	90	3	7	100	0	0
Blood loss	100	0	0	84	3	13	100	0	0	100	0	0
Mucus discharge	100	0	0	100	0	0	97	0	3	97	3	0
Incontinency	100	0	0	94	6	0	87	10	3	94	6	0
Abdominal cramps	100	0	0	77	13	10	97	3	0	94	6	0

Note: * data related to 31 patients

4.3.7. Late side effects

Only preliminary results are presented due to the low number of evaluable patients (19 pts) and the short follow up period with a mean of 15 months (range: 4–26). The distribution of the late genitourinary toxicity grades at the last visit was as follows: Gr. 0: 47%, Gr. 1: 11% and Gr. 2: 42%. The leading genitourinary symptom was dysuria (37%). One patient experienced Gr. 2 urgency and 1 patient developed Gr. 1 stricture at the bulbomembranous part of the urethra.

The distribution of the late gastrointestinal toxicity grades at the last visit was as follows: Gr. 0: 84%, Gr. 1: 11% and Gr. 2: 5% (soiling). Twelve months after the treatment 1 patient developed Gr. 2 proctitis, which is currently asymptomatic.

4.3.8. IPPS, EPIC

We have analyzed the changes in IPPS and EPIC scores for urination and bowel domains over time. IPSS increased from a median of 6 at baseline to 8 at 1 month, however from 3 months returned to the baseline value and remained stable till the first 12 months. Neither of the values were statistically different from baseline ($p = 0.8684$).

Baseline EPIC scores in the urinary, bowel domains ranged from 50 to 100%. No changes occurred in the bother domain scores. A decrease in urinary and bowel function occurred over the first 6 and 12 months, followed by an improvement up to the baseline conditions. Neither of the values showed statistically difference from the baseline scores ($p = 0.1406$).

4.3.9. Overall procedure time

The duration of the procedures for all patients from the beginning of patient positioning to the removal of the catheters, ranged

between 4.5 to 8.5 hours, with a mean of 6±1 hours. This mean value remained stable in the first and second half of the procedures (6±1.3 hours vs. 6±0.9 hours).

4.3.8. Biochemical control

The patient with low-risk cancer showed a marked decrease in the PSA from 9.57 ng/ml to 0.88 ng/ml after treatment.

The median PSA value for the remaining 33 patients with previous or undergoing antihomonal treatment was 0.014 ng/ml.

5. CONCLUSION

1. A system for transperineal MR-guided prostate intervention has been developed and applied successfully on *in vitro* and *in vivo* models. Needle placement accuracy, image quality were excellent and comparable with the international results. Image distorsion was found to be negligible also.

2. The developed MR-guided methodology has been completely and succesfully adopted to the human procedures and became a part of our daily clinical practice especially in the treatment of intermediate- and high risk prostate cancer patients. Based on our results following conclusions could be drawn

– The interventional procedures could be realized both in lateral decubitus- and in lithotomy position within the open configuration MR.

– The image quality was good to excellent with both imaging coil, with the note that the exact definition of the apical region and the neurovascular bundles at this level on the post-implant T2-FSE images could demand complementary image support.

– The catheter placement error is low and seems to be appropriate for MR-guided intervention. The major cause of the placement error is the catheter deflection within the tissues.

– Significant organ motion has been observed mainly toward the cranial direction after the first four needle insertions. This motion should be considered when using 14 G coaxial. The organ is fixed in this position, no relaxation was observed.

– Considering catheter placement accuracy and organ motion, catheter insertion within 5 mm margin around the organs at risk is not recommended. As a consequence of this result the inclusion of penile bulb as an organ at risk into the brachytherapy planning is unnecessary.

– The dosimetric results compared favorably with those published for HDR implants performed under MRI or TRUS.

– Optimal implantation and dosimetric outcome could be achieved in lateral decubitus position, also. The majority of the dosimetric results achieved in lithotomy position are significantly better. This difference could be rather explained by the increasing experiences, increased number of needles and the expanding priorities in treatment planning, than by the change in the positioning.

– The total working time is comparable with the MR-guided literature, however still significantly longer than with US guidance. The theoretical limit with our protocol would be 4–4.5 hours.

– Generally interventions were well tolerated. In lithotomy position the intervention tolerance was excellent.

– The rate of acute side effect is acceptable and comparable with the international literature. Majority of the side effects showed significant improvement over time. The genitourinary symptoms persist for a longer period.

– To determine late side effect, quality of life and outcome higher number of patients and longer follow up are needed.

3. MR-guided prostate HDR-BT could be a viable alternative of TRUS-guided procedures, if the increased staff-, time- and logistical workload could be managable. Selected patients could potentially benefit from MR-guided procedures.

Köszönetnyilvánítás

Dolgozatomban ismertetett eredményeink 4 év kutatómunkájának gyümölcse, amelynek eléréséhez egy munkacsoport áldozatos munkája, sok ember együttműködése szükségeltetett. A köszönetnyilvánításban azokat az embereket, kollegákat említem meg külön kiemelve, akik a legtöbbet segítettek munkám elvégzésében:

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A témához kapcsolódó tudományos közlemények

Publikációk

Open MR-guided high-dose-rate (HDR) prostate brachytherapy: feasibility and initial experiences. *Lakosi, F.*, Antal, G., Vandulek, C., Kovács, A., Bajzik, G, Rákász, I., Hadjiev. J., Repa, I., Bogner, P. – Pathology Oncology Research – közlésre elfogadott. Impact Factor: 1.26

Technical Feasibility of Transperineal MR-Guided Prostate Interventions in a Low-Field Open MRI Unit: Canine Study. *Lakosi, F.*, Antal, G., Vandulek, C., Kovács, A., Garamvölgyi, R., Petneházy, O., Bajzik, G., Hadjiev, J., Repa, I., Bogner, P. – Pathol Oncol Res 2009; 15:315–322. Impact Factor: 1.26

Az MR-képalkotással vezérelt prostata-brachytherapia metodikai tervezése. Az első magyarországi tapasztalatok állatkísérletes modellen. (MRI-guided prostate brachytherapy: First Hungarian experiences based on a canine study.) *Lakosi, F.*, Antal, G., Vandulek, Cs., Kotek, G., Kovács, A., Garamvölgyi, R., Petneházy, O., Hadjiev, J., Bajzik, G., Bogner, P., Repa, I. – Magyar Radiológia 2007; 81:224–229.

MR vezérelt prostata-brachytherapia: az első hazai tapasztalat. (MR-guided prostate brachytherapy: first hungarian experience.) *Lakosi, F.*, Antal, G., Vandulek, Cs., Kotek, G., Kovács, A., Bajzik, G., Rákász, I., Farkas, J., Kisbenedek, L., Kiss, I., Hadjiev, J., Repa, I., Bogner, P. – Magyar Urológia 2007; 19:197–203.

Előadások

MR vezérelt prostata brachytherápiás tapasztalatok. *Lakosi, F.,* Antal, G., Vandulek, Cs., Toller, G., Kovács, A., Hadjiev, J., Repa, I. – Magyar Radiológus Társaság XXV. Kongresszusa (2010, Kaposvár).

Open MRI-Guided HDR BT for Prostate Cancer: Feasibility and Initial Experiences. *Lakosi, F.,* Antal, G., Vandulek, Cs., Kovács, A., Pall, J., Rákász, I., Kiss, I., Hadjiev, J., Repa, I., Bogner, P. – Nucletron Users Meeting (2009, Budapest).

MR vezérelt HDR prosztata-brachyterápia: első hazai tapasztalatok. *Lakosi, F.*, Antal, G., Páll, J., Vandulek, Cs., Kovács, Á., Faour, A., Hadjiev, J., Rákász, I., Kiss, I., Repa, I., Bogner, P. – Magyar Sugárterápiás Társaság IX. Kongresszusa (2009, Pécs).

MR vezérelt prostata HDR brachyterápia Kaposváron: a megvalósítás küszöbén, *Lakosi, F.*, Antal, G., Vandulek, Cs., Kovács, Á., Garamvölgyi, R., Petneházy, Ö., Hadjiev, J., Bogner, P., Repa, I. – Magyar Sugárterápiás Társaság VIII. Kongresszusa (2007, Debrecen).

MR vezérelt prostate brachyterápia: első magyarországi tapasztalatok állatkísérletes modellen. *Lakosi, F.*, Antal, G., Vandulek, Cs., Kovács, Á., Garamvölgyi, R., Petneházy, Ö., Hadjiev, J., Bogner, P., Repa, I. – Fiatal Sebészek és Onkológusok Kongresszusa (2007, Kecskemét).

Abstractok

MR vezérelt prostata brachytherápiás tapasztalatok. *Lakosi, F.,* Antal, G., Vandulek, Cs., Toller, G., Kovács, A., Hadjiev, J., Repa, I. – Magyar

Radiológus Társaság XXV. Kongresszusa (2010, Kaposvár). Magyar Radiológia Vol 84. (No. 2); Június 2010.

MRI Modelling of Rectal Dosimeter Probe during MRI-Guided HDR BT for prostate: Feasibility and Initial Experiences. Antal, *G., Lakosi,* F., Vandulek, Cs., Kovács, A., Glavák, Cs., Rákász, I., Kiss, I., Hadjiev, J., Repa, I., Bogner, P. – Journal of Contemporary Brachytherapy Vol 1. (No. 3); July–September 2009.

Open MRI-Guided HDR BT for Prostate Cancer: Feasibility and Initial Experiences. *Lakosi, F.,* Antal, G., Vandulek, Cs., Kovács, A., Pall, J., Rákász, I., Kiss, I., Hadjiev, J., Repa, I., Bogner, P. – Journal of Contemporary Brachytherapy Vol 1. (No. 3); July–September 2009.

MR vezérelt HDR prosztata-brachyterápia: első hazai tapasztalatok. *Lakosi,* F., Antal, G., Vandulek, Cs., Kovács, Á., Garamvölgyi, R., Petneházy, Ö., Hadjiev, J., Bogner, P., Repa, I. – Magyar Onkológia Vol. 53. (No. 2); Június 2009.

MR vezérelt prosztata-brachytherápiás kezelés in vivo rektális dozimetriája. Antal, G., *Lakosi, F.,* Vandulek, Cs., Kovács, Á., Glavák, Cs., Hadjiev, J., Rákász, I., Farkas, J., Bogner, P., Repa, I. – Magyar Onkológia Vol. 53. (No. 2); Június 2009

MR imaging-guided high-dose-rate (HDR) prostate brachytherapy in a low-field open MR unit: Feasibility and initial experiencies. *Lakosi,* F., Antal, G., Vandulek, Cs., Kovács, A., Hadjiev, J., Bogner, P., Repa, I. – Radiotherapy and Oncology Vol. 88. Suppl 2. September 2008. Impact Factor: 3.99

MR-guided prostate brachytherapy in a low-field open MR system: canine and in vitro dosimetry study. Antal, G., *Lakosi,* F., Vandulek, Cs., Garamvölgyi, R., Petneházy, Ö., Kovács, A., Hadjiev, J., Bogner, P., Repa, I. – European Journal of Cancer EJC suppls Vol. 5. (No. 4); September 2007. Impact Factor: 4.454

Teshnical feasibility of transperineal MR-guided prostate interventions in a low field open MR syste: canine study. *Lakosi,* F., Antal, G., Vandulek, Cs., Garamvölgyi, R., Petneházy, Ö., Kovács, A., Hadjiev, J., Bogner, P., Repa, I. – Radiotherapy and Oncology Vol. 83. Suppl 1 May 2007. Impact Factor: 4.074