Original Article

PROGRESS in MEDICAL PHYSICS Vol. 24, No. 4, December, 2013
http://dx.doi.org/10.14316/pmp.2013.24.4.237

The Feasibility Study of MRI-based Radiotherapy Treatment Planning Using Look Up Table

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In the intracranial regions, an accurate delineation of the target volume has been difficult with only the CT data due to poor soft tissue contrast of CT images. Therefore, the magnetic resonance images (MRI) for the delineation of the target volumes were widely used. To calculate dose distributions with MRI-based RTP, the electron density (ED) mapping concept from the diagnostic CT images and the pseudo CT concept from the MRI were introduced. In this study, the look up table (LUT) from the fifteen patients' diagnostic brain MRI images was created to verify the feasibility of MRI-based RTP. The dose distributions from the MRI-based calculations were compared to the original CT-based calculation. One MRI set has ED information from LUT (*l*MRI). Another set was generated with voxel values assigned with a homogeneous density of water (*w*MRI). A simple plan with a single anterior 6MV one portal was applied to the CT, *l*MRI, and *w*MRI. Depending on the patient's target geometry for the 3D conformal plan, 6MV photon beams and from two to five gantry portals were used. The differences of the dose distribution and DVH between the *l*MRI based and CT-based plan were smaller than the *w*MRI-based plan. The dose difference of *w*MRI vs. *l*MRI was measured as 91 cGy vs. 57 cGy at maximum dose, 74 cGt vs. 42 cGy at mean dose, and 94 cGy vs. 53 at minimum dose. The differences of maximum dose, minimum dose, and mean dose of the *w*MRI-based plan were lower than the *l*MRI-based plan, because the air cavity was not calculated in the *w*MRI-based plan. These results prove the feasibility of the *l*MRI-based planning for brain tumor radiation therapy.

Key Words: MRI-based RTP, Look up table, Electron density

INTRODUCTION

Computed tomography (CT) has been the basis for the radiation treatment planning (RTP) because of its direct connection to the electron density (ED).[1)] However, in the intracranial regions, an accurate delineation of the target volume has been difficult with only the CT data due to poor soft tissue contrast of CT images. Therefore, the magnetic resonance images (MRI) for the delineation of the target volumes were widely used.[2)] The most common RTP procedure consists of an image fusion with MRI and CT image for the calculation of dose distribution. Currently, an MRI and CT image fusion for dose calculation is the standard for brain tumor, prostate cancer, and spine tumor.[3)] Some authors, however, refer to the additional uncertainty which was occurred from the registrations between CT and MRI.[4)] The error introduced from the registration will systematically affect the radiation therapy throughout the entire treatment period. In order to calculate dose distribution with

This work was supported by the fusion research program of Korea research council for industrial science and technology (B551179-12-08-00, Development of Convergent Radio Therapy Equipment with O-arm CT) funded by the Ministry of Trade, Industry&Energy (MOTIE, Korea).
Submitted November, 29, 2013, Accepted December, 9, 2013
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MRI-based RTP, other authors introduced the ED mapping concept from the diagnostic CT images and the pseudo CT concept from the MRI.[5,6] The ED mapping concept showed very close difference of dose distributions with the CT-based RTP as less than 2% dosimetric errors. And Pseudo-CT concept proved the feasibility of MR-baed RTP, for instance generation of DRRs from MRI. Because the ED mapping concept has still dependence with the CT images, the look up table (LUT) from the fifteen patients' diagnostic brain MRI images was created to verify the feasibility of MRI-based RTP. The aim of this study was therefore to compare MRI-based calculations and original CT-based calculation on the basis of dose distributions.

MATERIAL AND METHODS

1. Data acquisitions for manufacturing look up table (LUT)

We collected fifteen patients' brain MRI image and measured gray scale of brain soft tissue, eyeball, nasal cavity and bone using the Image J (freeware, http://rsbweb.nih.gov/ij/). The ED and major components were big differences at brain soft tissue, eyeball, nasal cavity and bone. The MRI images were acquired on an MRI (Skyra 3T, Simens, Germany) by TE 2.5 ms, and TR 250 ms FOV 220×220, pixel size 320×320 and not used contrast medium. Fig. 1 shows the brain MRI image and chosen region of interest (ROI).

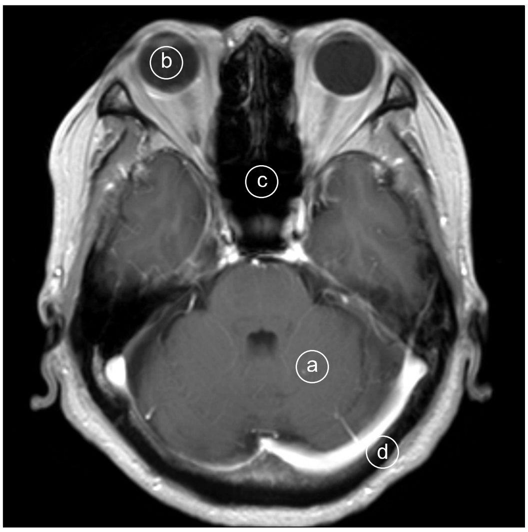

Fig. 1. The OARs are contoured on the magnetic resonance images (MRI) in order to define the gray scales; (a) The brain soft tissue, (b) Eyeball, (c) Nasal cavity, and (d) Bone.

2. Treatment planning using MRI-based and CT based

We used the MRI data from fifteen brain tumor patients. The CT data were acquired from a CT simulator (Light speed 16, GE, USA) with a 480 mm FOV, matrix 512×512 (pixel resolution 0.94 mm), and 2.5 mm thickness. The MRI data were acquired on a Skyra 3T MR. The image acquired condition was like a manufacturing LUT. We used two MRI image sets for treatment planning. One MRI set has the ED information from LUT (*l*MRI). Another set was generated with voxel values assigned with a homogeneous density of water (*w*MRI). The clinical target volume (CTV) and the OARs (i.e. eyes, eye lenses, optic nerves, optic chiasm, pituitary gland and brain stem) were contoured by one radiation oncologist in the CT enhancement image and T1-weighted uncorrected datasets using the typical contouring tools available in RTPs (Core plan, SCNJ, Korea). Three dimensional uniform margins of 5 mm were added to the CTV in order to generate the planning target volume (PTV).

The RTPs version was used for the study, which is capable of performing dose calculation in a MRI. We inserted LUT in RTPs and adapted to MRI.

The MRI-based plans were generated, only for plan comparison, using the same planning parameters as for CT-based planning in terms of the prescribed dose, fractions, beam energy, and beam angles. A simple plan with a single anterior 6MV 10 cm×10 cm one portal was applied to the CT, *l*MRI, and *w*MRI. We used 6 MV photon beams and a two to five gantry portal depending on the patient's target geometry for 3D conformal plan.

3. CT-based and MRI-based planning comparison

We evaluated the proposed MRI-based treatment planning procedure using 3T MR clinical studies to compare MR and CT-based treatment plans in terms of the OARs, including optic nerve, lens, brain stem, eyeball, and PTV. To compare the plans we used isodose distributions, dose volume histograms (DVHs) and several PTV dosimetric parameters, i.e. the dose at the isocenter dose (D_{iso}), mean target dose (D_{mean}), minimum target dose (D_{min}) and maximum target dose (D_{max}).

RESULTS

1. Data for manufacturing look up table (LUT)

Table 1 shows the gray scales of the fifteen patients' OARs. The gray scale range is 533～739 (brain soft tissue), 226～329 (eyeball), 9.6～98 (nasal cavity), and 1024～1414 (bone). Fig. 2 shows the converted gray scale to CT density data.

2. CT-based and MRI-based planning comparison

Fig. 3 shows the isodose dose distributions of the 10 cm× 10 cm one portal plan generated based CT, *l*MRI and *w*MRI. Fig. 4 is the comparison of brainstem DVH for CT and MR based radiation therapy plans. The difference in dose distribution and DVH between *l*MRI-based and CT-based plan was smaller than a *w*MRI-based plan. The maximum dose of the *w*MRI-based plan was lower than the *l*MRI-based plan.

Fig. 5 shows the 15 patients average maximum dose difference between *w*MRI and *l*MRI based plans. The reference dose was the CT-based plans. The maximum dose difference between *l*MRI-based plans and CT-based plans were smaller than the *w*MRI-based plans and CT-based plans. The biggest difference of the maximum dose was the brain stem dose. There was 91 cGy dose difference between *w*MRI-based plans and CT-based plans. But there was a 57 cGy dose difference between *l*MRI based-plans and CT-based plans.

Fig. 6 shows the 15 patient averages mean dose difference between *w*MRI and *l*MRI based plans. The reference dose was the CT-based plans. The mean dose difference between *l*MRI-based plans and CT-based plans was smaller than

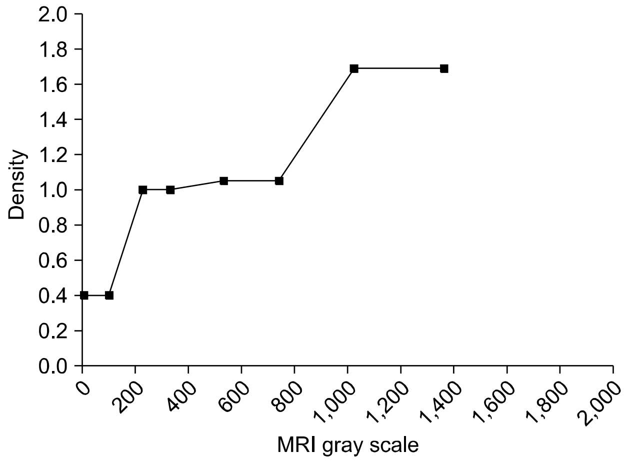

Fig. 2. Gray scales of MRI are converted to the CT density via the look up table (LUT).

Table 1. General patients' information and patients' gray scale data at OARs.

Patients	Age	Gender	Diagnosis	Brain	Eyeball	Cavity	Bone
1	57	Male	Glioblastoma	739	329	98	1,277
2	49	Male	Glioblastoma	701	283	21	1,362
3	51	Male	Anaplastic astrocytoma	747	306	54	1,261
4	63	Female	Anaplastic oligdendroglioma	778	328	15	1,414
5	38	Female	Glioblastoma	721	318	17	1,119
6	41	Male	Glioblastoma	616	307	9.9	1,217
7	71	Female	Anaplastic oligdendroglioma	624	294	65	1,223
8	38	Female	Glioblastoma	539	226	16	1,024
9	44	Male	Glioblastoma	694	305	19	1,178
10	50	Male	Anaplastic oligdendroglioma	719	307	39	1,152
11	51	Female	Glioblastoma	645	292	45	1,220
12	74	Female	Glioblastoma	637	275	14	1,182
13	81	Female	Glioblastoma	533	235	19	1,116
14	35	Male	Anaplastic astrocytoma	658	293	9.7	1,348
15	41	Female	Anaplastic astrocytoma	652	294	9.6	1,207
Range	35～81			533～739	226～329	9.6～98	1,024～1,362
Average	52.3			666.9	292.8	30.1	1,220.0
SD*	14.2			71.7	29.4	25.5	102.3

*Standard deviation.

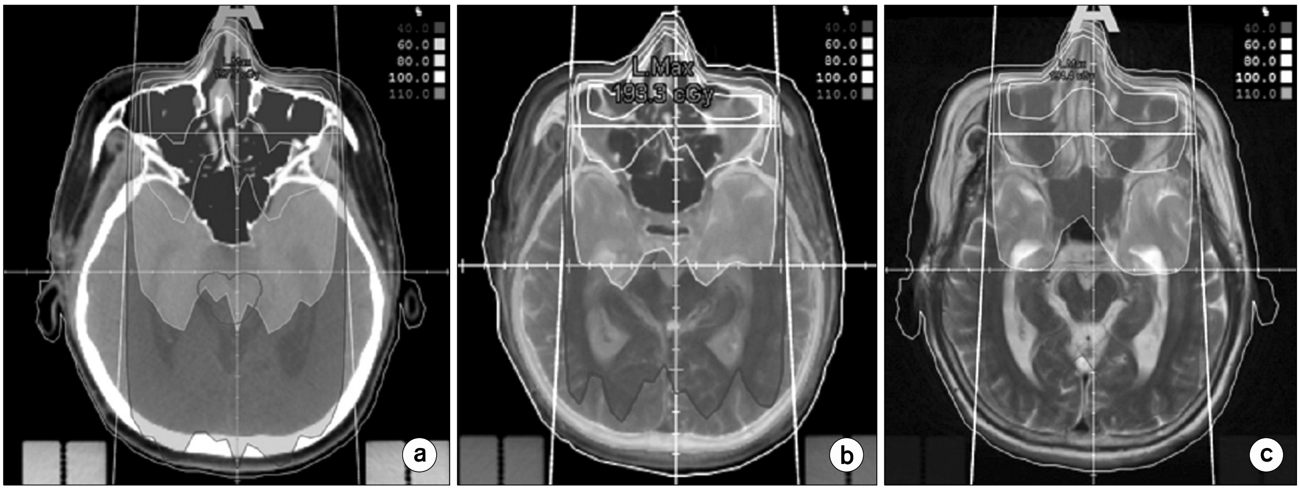

Fig. 3. Dose distributions are shown on the CT image and MR images (a) CT-based isodose curve, (b) *l*MRI-based isodose curve, and (c) *w*MRI-based isodose curve.

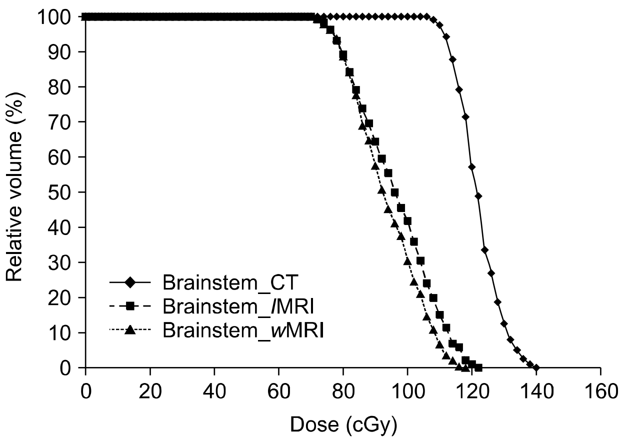

Fig. 4. The CT and MR based radiation therapy plans were compared with the DVH of brainstem.

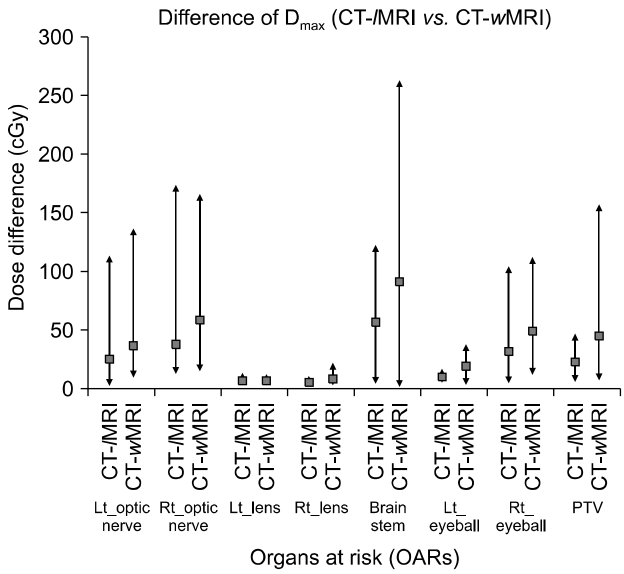

Fig. 5. 15 patients average maximum dose difference between *w*MRI and *l*MRI based plans. The reference dose were CT-based plans.

*w*MRI-based plans and CT-based plans. The biggest difference of the mean dose was the PTV dose. The dose difference was 74 cGy between *w*MRI-based plans and CT-based plans. But the dose difference was 42 cGy between *l*MRI-based plans and CT-based plans.

Fig. 7 shows the 15 patient averages minimum dose difference between *w*MRI and *l*MRI based plans. The reference dose is the CT based plans. The minimum dose difference between *l*MRI-based plans and CT-based plans was smaller than *w*MRI-based plans and CT-based plans. The biggest difference of minimum dose is the PTV dose. The dose difference was 94 cGy between *w*MRI-based plans and CT based plans. The dose difference was at 53 cGy between *w*MRI-based plans and CT-based plans.

DISCUSSION AND CONCLUSION

We developed RTP for MRI-based planning for this study. To ensure the dose calculation accuracy of MRI-based planning, 15 patients' brain MRI images were obtained and meas-

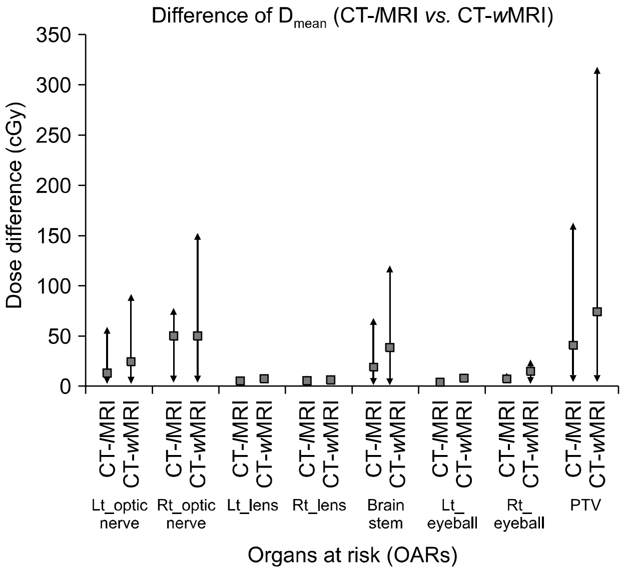

Fig. 6. 15 patients average mean dose difference between *w*MRI and *l*MRI based plans. The reference dose were CT-based plans.

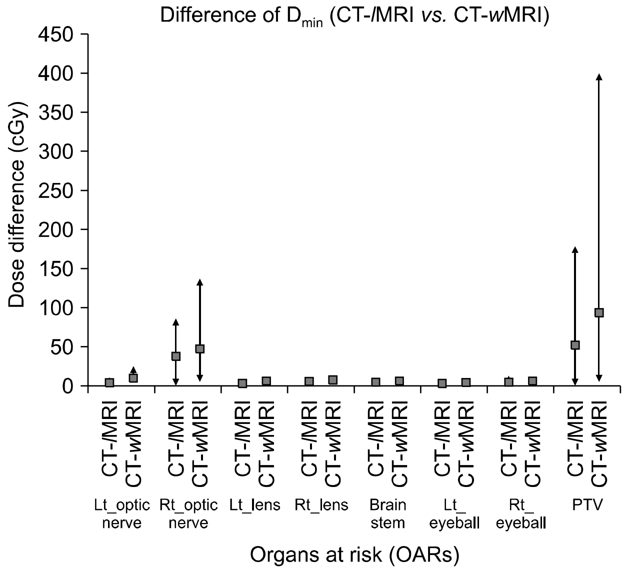

Fig. 7. 15 patients average minimum dose difference between *w*MRI and *l*MRI based plans. The reference dose were CT-based plans.

ured the gray scale of the brain tissue, nasal cavity, bone and eyeball. Fig. 3 and Fig. 4 show that the *l*MRI-based plan was a little bit different to the *w*MRI-based plan. The *w*MRI-based plan did not calculate the air cavity and calculate it as the same density with water. The isodose curve of the CT-based plan was differ than a MRI-based plan, because of the air cavity. Fig. 5, Fig. 6 and Fig. 7 shows the dose difference between the CT-based plan and MRI-based plans. The dose difference of *l*MRI-based plans was smaller than the *w*MRI-based plans at all OARs and PTV. The dose difference at the optic nerve, brain stem, and PTV was bigger than the lens and eyeball. This is because the optic nerve brain stem and PTV were located in a nearby air cavity. When the radiation beam passed through the air cavity or OAR located in a nearby air cavity, the dose difference was larger than in the tissue.

As a result, *l*MRI-based plans were superior to the *w*MRI-based plans at all OARs and PTV. Therefore, the feasibility of the *l*MRI-based planning was proved in the case of brain tumor radiation therapy. If there are adequate additional studies are performed, the accuracy of MRI-based plans would be improved.

Future studies are needed for more accurate MRI-based plan. Abundant patients' MR images should be obtained to measure the gray scales of OARs and target volumes. Moreover, more concerns about the inherent MR images' distortion and the obtained MR images' deformation should be considered in order to well compare to the CT-based plan. Various types of MR images, including T1-weighted, T2-weighted, and proton density scan, would be also measured and evaluated for the improved MR-based plan.

Furthermore, the comparison with the ED mapping methods would be one of the future studies. After that we can utilize the intensity modulated radiation therapy in intracranial regions with the less difference with CT-based plan.

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Look Up Table을 이용한 자기공명영상 기반 방사선 치료계획의 타당성 분석 연구

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뇌병변 등의 방사선 치료에 있어 CT (Computed Tomography) 영상만을 이용한 종양 체적(Tumor volume) 윤곽의 정확한 설정은 CT 영상의 부족한 연부조직 대조도 특성에 의하여 한계를 가진다. 따라서 자기공명영상(Magnetic Resonance Images, MRI)이 보다 정확한 목표 체적의 윤곽을 그려내기 위해 광범위 하게 사용되고 있다. 치료계획을 위해 획득한 자기공명영상에 진단단계에서 얻어진 CT영상의 전자밀도를 융합하는 방법과 자기공명 영상으로부터 만들어진 가상의 CT를 이용하는 방법 등이 자기공명 영상장치를 기반으로 한 방사선 치료 계획의 선량계산을 위하여 소개되어 왔다. 본 연구는 MRI기반의 선량계산의 가능성을 확인 해보기 위해 15명 환자의 진단 MR 영상을 통하여 Look Up Table (LUT)을 만들어 MRI 기반 선량계산과 기존의 CT 기반 선량계산을 비교 검증 하였다. 여기서 lMRI는 획득한 MR 영상에 LUT를 이용한 전자밀도 보정을 한 것이며 *w*MRI는 획득한 MR영상을 물 밀도로 동일화 시킨 것이다. 6 MV anterial 방향의 조사가 CT, lMRI, *w*MRI에 적용되어 치료계획으로 비교되었으며 또한 환자의 병변위치에 따라 2문 조사에서 5문 조사의 치료계획이 비교되었다. CT기반 치료계획을 기준으로 하여 등선량 분포와 DVH의 차이는 *w*MRI 보다 *l*MRI에서 더 적었으며 최대선량 차이가 91 cGy vs. 57 cGy, 평균선량이 74 cGy vs. 42 cGy, 최소선량 차이가 94 cGy vs. 53 cGy로 측정되어 각각의 선량 평가 면에서 그 차이가 *w*MRI보다 *l*MRI에서 더 적었다. 이러한 결과는 *w*MRI의 경우 공동내 선량계산에서 CT 기반 선량계산과 차이가 나기 때문이다. 따라서 본 연구의 결과는 lMRI 기반 선량계산의 가능성이 있음을 보여준다.

중심단어: 자기공명영상기반 방사선치료계획시스템, Look up table, 전자밀도