



Radiotherapy treatment planning: benefits of CT-MR image registration and fusion in tumor volume delineation

Planiranje radioterapije: značaj registracija i fuzije CT-MR slike za određivanje zapremine tumora

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Abstract

Background/Aim. Development of imaging techniques, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET), made great impact on radiotherapy treatment planning by improving the localization of target volumes. Improved localization allows better local control of tumor volumes, but also minimizes geographical misses. Mutual information is obtained by registration and fusion of images achieved manually or automatically. The aim of this study was to validate the CT-MRI image fusion method and compare delineation obtained by CT versus CT-MRI image fusion. **Methods.** The image fusion software (XIO CMS 4.50.0) was applied to delineate 16 patients. The patients were scanned on CT and MRI in the treatment position within an immobilization device before the initial treatment. The gross tumor volume (GTV) and clinical target volume (CTV) were delineated on CT alone and on CT+MRI images consecutively and image fusion was obtained. **Results.** Image fusion showed that CTV delineated on a CT image study set is mainly inadequate for treatment planning, in comparison with CTV delineated on CT-MRI fused image study set. Fusion of different modalities enables the most accurate target volume delineation. **Conclusion.** This study shows that registration and image fusion allows precise target localization in terms of GTV and CTV and local disease control.

Key words:

radiotherapy; radiotherapy planning, computer-assisted; tomography, x-ray computed; magnetic resonance imaging.

Apstrakt

Uvod/Cilj. Brzi razvoj tehnika snimanja kao što su kompjuterska tomografija (CT), magnetska rezonanca (MR), i pozitronska emisiona tomografija (PET), ima veliki uticaj na kvalitet individualnih radioterapijskih planova, u smislu bolje lokalizacije tumora. Bolje lokalizovanje tumora podrazumeva i bolju lokalnu kontrolu bolesti. Spajanje CT, MR i PET slika u jednu (registracija i fuzija slike) može se izvesti automatski ili manuelno. Cilj ovog rada bio je da se proceni upotrebljivost fuzije i uporedi delineacija tumora sa CT preseka i sa slike dobijene fuzijom CT-MR. **Metode.** Softver za planiranje radioterapije i fuziju slike (XIO CMS 4.50.0) primenjen je kod 16 bolesnika. Bolesnici su snimljeni na CT i MR u istim pozicijama u kojima će se i zračiti. Ukupni (GTV) i klinički volumeni tumora (CTV) određeni su prema protokolu na kompletu CT slika, a zatim, nakon fuzije CT sa MR, i na novonastalom kompletu snimaka. **Rezultati.** Fuzija slike pokazala je da je CTV određen samo sa CT snimaka uglavnom neadekvatan za planiranje terapije, odnosno da fuzija informacije sa CT i MRI omogućuje mnogo preciznije i bolje određivanje kontura tumora. **Zaključak.** Registracija, a potom i fuzija slike CT-MR, omogućuje najprecizniju moguću lokalizaciju tumora (GTV) i volumena kliničkog širenja bolesti (CTV), kao i bolju lokalnu kontrolu bolesti.

Ključne reči:

radioterapija; radioterapija, kompjutersko planiranje; tomografija, kompjuterizovana, rendgenska; magnetska rezonanca, snimanje.

Introduction

Medical imaging techniques in the past decades became crucial for medical diagnosis or analyses. Techniques such as X-rays, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) enabled

different approaches and insights of human body, important for analysis and diagnosis. For example, CT scans provide high resolution information on bony structure while MRI scans provide detailed information on tissue types within the body¹.

Precise determination of target volumes is the most crucial and difficult part of radiotherapy (RT) planning process,

especially because modern RT planning techniques such as conformal RT (CRT) and intensity-modulated RT (IMRT) are used. Otherwise, a geographical miss of a tumor or a systematic error will go on throughout the therapy. In order to avoid such problem, MRI is being increasingly used in oncology not only for staging, assessing tumor response and evaluating disease recurrence, but also for delineation of target volume in RT². The improved characterization of soft tissues and visualization of tumour extent using MRI can be used to benefit the RT treatment planning (RTP) process from delineation of target volumes to determining planning margins and treatment response³.

Standard RTP uses CT data that provide good distinguishing between structures that have substantially different X-ray attenuation properties or Hounsfield units, such as among air, tissue and bone. On the other hand, it is more difficult to discriminate between soft tissue structures with similar electron densities, including tumors⁴.

Correct determination of tumor localization and extension is of major importance in radiation oncology. Modern RT techniques require the increased sophistication of different imaging modalities. With image fusion protocols it is possible to use both, the diagnostic superiority of MRI and the geometric superiority of CT^{5,6}. CT-MRI image fusion provides better tissue discrimination, and distinguishing between tumor with its boundaries of infiltration and the adjacent normal structures. In this manner, CT-MRI fusion provides improved target delineation for RTP. This approach applies not only to the initial RT treatment of tumors, but also potentially to re-treatments by being able to differentiate between changes due to recurrent cancer or that secondary to post-treatment fibrosis. It can also provide better delineation of organs at risk (OARs) for dose avoidance in RTP⁴.

The aim of this research was to determine and present the most interesting cases challenging for the delineation of target volumes using CT only, that were successfully solved and in which the delineation process was successfully finished using CT-MRI fusion. As we know, this method has not been used at clinics of radiotherapy in our country so far.

Methods

A total of 16 patients with intracranial tumors were prepared for standard RT treatment. The CT scanner used was SIEMENS Somatom plus. Each patient was scanned in treatment position, with an immobilization applied. CT data were then exported from CT and imported to the RT treatment planning system. The MR data sets were obtained by a Siemens Avanto or Siemens Magnetom Trio. The patients were scanned according to the standard diagnostic protocol, and stored to the hospital Picture Archiving and Communications System (PACS).

The first step correlating CT and MR images is image registration. Image registration is the process in which two image data sets are put into the common coordinate system. The most often is a combination of CT and MR images, where CT set is used as a reference, and MR set is reoriented and registered to the CT coordinate system. Finally, two im-

ages can be fused (blended into a single image), where one, or another image can be more or less weighted for visualization (Figure 1). Practically, it is done with the fusion license of a treatment planning software (XIO CMS v.4.50.0).

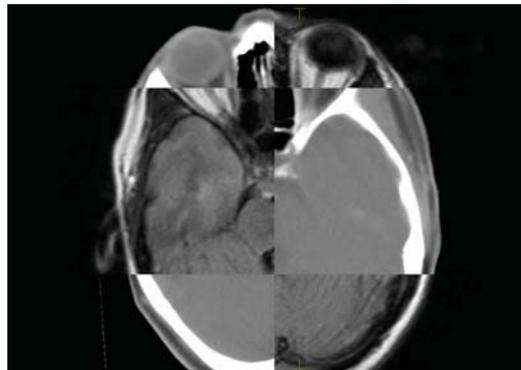


Fig. 1 – Computed tomography–magnetic resonance imaging (CT-MRI) fusion

An RTP system with fusion licence, enables registration and fusion of different DICOM modalities [CT, MR, PET, single-photon emission computed tomography (SPECT)...] The hospital's PACS archives all patients DICOM files, which could be used and retrieved at any time. The requested data set (MR) for the selected patient is obtained via the network, and imported into the treatment planning system XIO CMS. The patient's data (CT and MR) were loaded, one by one, and automatically registered and fused (Figure 2). Fusion software allows manual rotation and movement in all

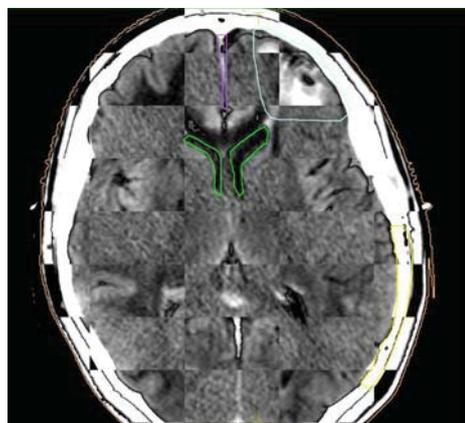


Fig. 2 – Computed tomography–magnetic resonance imaging (CT-MRI) fusion with delineated falx cerebri (violet line), cornu anterius ventriculi lateralis (green line) and astrocytoma gr. II (blue cyan line)

the three spatial directions, and enables corrections of a patient position, if it is changed between the two imaging sessions (CT and MR). Registration and fusion was immediately visually evaluated. Visual inspection of all slices and cross-sections means that registration and fusion have actually passed individual quality control, i.e. verification of resulting image matching⁷. Manual correction of image registration was necessary in some cases, depending on the matching results, i.e. quality of CT and MR data in certain

areas of the brain. The next step was delineation of target volumes, gross tumor volume (GTV), clinical target volume (CTV), planing target volume (PTV) and the organs at risk, according to recommendations⁸. CTV was determined by adding 10 mm on the GTV^{8,9}.

Results

The CT and MR images of all sixteen patients included were successfully fused. Of them, in 4 patients preoperative MRI was used and in the others MRI was performed before CT as a part of the planning process for RT treatment, for the patients with surgery treatment or those without surgery treatment. The results of completed delineation of target volumes using MRI-CT fusion are shown in three different cases, chosen as representative results. One of them belonged to the group with preoperative MRI, and the after two were the second group patients. The successful fusion and delineation process was obtained for all the patients, and the shown cases were randomly chosen.

The first patient had the diagnosis of vestibulocochlear nerve schwannoma on the right side. CT imaging (Figure 3a) failed to provide clear boundaries of schwannoma. MRI (Figure 3b) solely could not be used for the planning process, since the treatment planning system calculations are based on CT electron density data. The effectiveness of medical image fusion can be illustrated by this example (Figure 3c). CT-

MRI fusion provided clear boundaries of schwannoma visualized by MRI T2 sequence together with CT image required for precise RT delineation and planning.

The second patient had the diagnosis of low-grade multicentric astrocytoma of the left cerebral hemisphere. The patient underwent stereotactic brain biopsy, which was positive for low-grade II astrocytoma. MRI (Figure 4b) revealed tumor expansive tissue with perifocal edema with clear boundaries. Edema boundaries revealed on MRI T2 sequence were GTV. CT image (Figure 4a) showed tumor with unclear edema boundaries insufficient and not enough sophisticated for the best RT delineation. Comparison between PTV according to CT (green line) and MRI (yellow line) is showed in Figure 4c.

The third patient had the diagnosis of low-grade astrocytoma. After the surgery a small part of tumor tissue was left due to localization. For this patient, RT planning process included preoperative MRI T2 sequence for CT-MRI fusion to encompass all micrometastases. Postoperative MRI was also done, as well as comparison of pre- and postoperative MRI revealing that the broader area should be included, which encouraged the usage of preoperative MRI for CT-MRI fusion in this case. Application of CT-MRI fusion revealed better boundaries of the tumor compared to CT only, especially due to the left part of the tumor (Figure 5.). CT-MRI fusion provided more precise localization of edema surrounding tumor tissue, which enables more precise determination of target volumes.

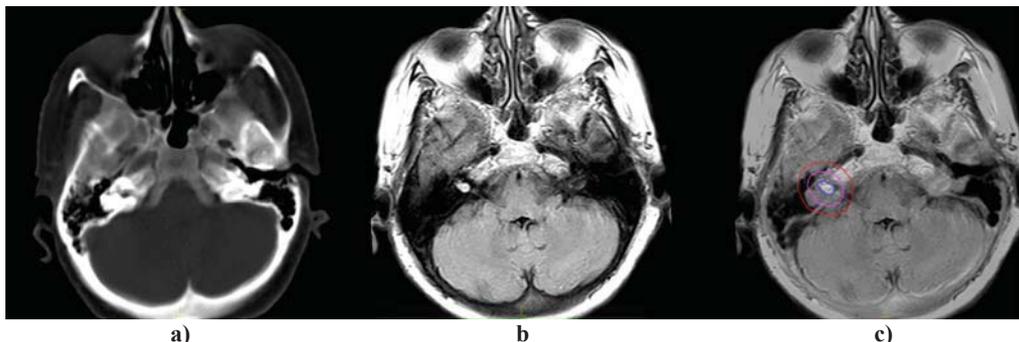


Fig. 3 – a) Computed tomography (CT) of intracranial schwannoma on the right side; b) Computed tomography – magnetic resonance imaging (CT-MRI) T2 sequence of the same section as given in 3a; c) CT-MRI fusion and delineation of target volumes.

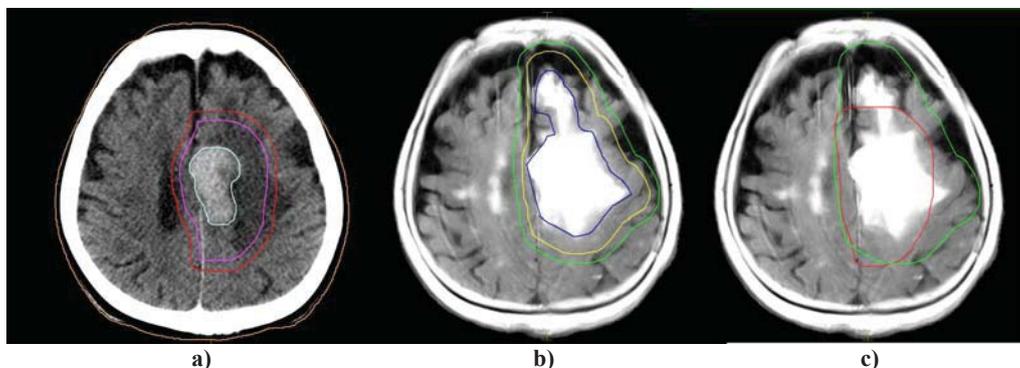


Fig. 4 – a) Computed tomography (CT) image with gross tumor volume (GTV), clinical target volume (CTV) and planning target volume (PTV); b) Magnetic resonance imaging (MRI) T2 sequence with GTV, CTV and PTV; c) Comparison between PTV according to CT (red line) and MRI (green line).



Fig. 5 – Astrocytoma gradus II located in the left frontal lobe.

Discussion

CT-MRI fusion at the Institute of Oncology Vojvodina was proved to be very important. In our relatively short time period experience, CT-MRI fusion was applied in 16 patients. Three patients with different CT-MRI benefit were chosen in order to present advantages of this method.

In all the showed cases, applied imaging techniques were followed by delineation of target volumes.

CT-MRI fusion in the patient with schwannoma diagnosis enabled more precise target volume delineation, due to advancements provided by MRI comparing to CT imaging in distinguishing between tissues with similar densities. Without MRI, neither GTV, nor CTV would be appropriate, due to unadequate visualization. There should be a possibility of either larger target volume in order to be sure that necessary region is treated or insufficient target volume to prevent large dose application to adjacent organs at risk. Subsequently, the organs at risk such as cochlea and inner ear, would be exposed to higher dose. A large number of authors stress advantages of MRI comparing to CT for the evaluation¹⁰ and delineation of target volumes¹¹ for auditory and vestibular systems pathology. Bartling et al.¹² advice using of CT-MRI fusion in temporal bone pathology RT treatment.

Maybe the more obvious example of problems that can arise without CT-MRI fusion is showed by the patient with low-grade multicentric astrocytoma (case 2). This example gives data of insufficient visualization for low-grade and high-grade gliomas by CT in some cases. Usage of T2 sequence MRI or FLAIR^{8,9} for delineation, decreases chances for lower dose or geographical miss for tumor RT treatment, since tumor and edema could be precisely verified. After delineation of CTV (GTV (T2 sequence)+10m), 5 mm are added for PTV. Usage of T2 sequence MRI or FLAIR for GTV and addition of 10 mm for CTV the most probably encounters micrometastatic extants. We decided to use these recommendations since there were studies reporting micrometastasis out of T2 sequences, especially in high-grade astrocytomas and gliomas¹³.

The third patient in our study had the same diagnosis as the second one, but this patient had underwent surgery treatment. Even though postoperative MRI was done, we have decided to use preoperative MRI in order to include larger area to provide encountering of all micrometastasis possible after surgery. Usage of preoperative MRI in CT-MRI fusion enabled determination of initial tumor size and during delineation according to that size to decrease possibility for geographical miss.

Both CT and MRI provide very good, but not identical, information on macro- and microscopic tumor extension. In the ideal situation the target volume is delineated based on pre- and postoperative CT and MRI. This set of data is used for constructing composite target volumes. With image fusion protocols it is possible to use both the diagnostic superiority of MRI and the geometric superiority of CT in 3D RTP^{6,13,14}.

Conclusion

This paper illustrates the effectiveness of medical image fusion. It also proves that medical image fusion is a powerful technique for medical imaging analysis. Image fusion allows better visualization for RT delineation and planning of target volumes. CT-MRI fusion provides even better estimation of target volumes that may permit treatment individualization, organ sparing or functional avoidance. It is also clear, although not emphasized here, that CT-MRI fusion allows strategies of boosting and dose escalation. Future dynamic imaging modalities like, PET, SPECT and functional MRI should be included in our practice.

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