Original Article

Evaluation of Effective Parameters on Quality of Magnetic Resonance Imaging-computed Tomography Image Fusion in Head and Neck Tumors for Application in Treatment Planning

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Abstract

Background: In radiation therapy, computed tomography (CT) simulation is used for treatment planning to define the location of tumor. Magnetic resonance imaging (MRI)-CT image fusion leads to more efficient tumor contouring. This work tried to identify the practical issues for the combination of CT and MRI images in real clinical cases. The effect of various factors is evaluated on image fusion quality. **Materials and Methods:** In this study, the data of thirty patients with brain tumors were used for image fusion. The effect of several parameters on possibility and quality of image fusion was evaluated. These parameters include angles of the patient's head on the bed, slices thickness, slice gap, and height of the patient's head. **Results:** According to the results, the first dominating factor on quality of image fusion was the difference slice gap between CT and MRI images (cor = 0.86, $P < 0.005$) and second factor was the angle between CT and MRI slice in the sagittal plane (cor = 0.75, $P < 0.005$). In 20% of patients, this angle was more than 28° and image fusion was not efficient. In 17% of patients, difference slice gap in CT and MRI was >4 cm and image fusion quality was <25%. **Conclusion:** The most important problem in image fusion is that MRI images are taken without regard to their use in treatment planning. In general, parameters related to the patient position during MRI imaging should be chosen to be consistent with CT images of the patient in terms of location and angle.

Keywords: *Computed tomography, image fusion, magnetic resonance imaging, treatment planning*

Introduction

One of the basic procedures for cancer treatment is radiotherapy that in some cases, it is used with other methods such as chemotherapy, surgery, and gene-therapy.[1-3] Radiotherapy is an irreversible method that in case of error in dose delivery, depending on the type of disease, it leads to delay or stopping treatment or irrecoverable injury to the patient.[4,5] The most common method in radiotherapy is three-dimensional (3D) conformal radiation therapy. It is a complex process that uses the two-dimensional (2D) images of the tumor to produce 3D data of the tumor and its surrounding tissues.[6-10] Treatment planning process is based on focused radiation beams toward the tumor site to reduce patient dose. Radiotherapy is used to damage cancer cells while preserving normal tissues.[11,12]

The most basic and one of the most important steps of the treatment planning is diagnosing stage during which the doctor (oncologist, also in some case physician) detects the location of the tumor and its possible expansion.[13] The lack of accurate detection of the size and location of tumors in radiation therapy can lead to increased patient dose, incomplete destruction process of cancer cells, receiving additional doses in normal tissue, and incorrect treatment. It means tumor growth and disease progression in steps that doctor imagines the disease is under control and treatment.[14] The treatment planning system (TPS) is based on computed tomography (CT) scan images and prescribed dose to the tumor.[15] According to the inherent features of CT images, the value of a pixel in the CT image is calculated by comparing the linear attenuation coefficient of tissue with linear attenuation coefficient of water.[16] CT images in treatment planning are used as the gold standard. Based on the CT number of each pixel, electron density of tissue is

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indicated, and finally, for each point, the absorbed dose can be calculated.[17]

In radiation therapy, CT simulation is used for treatment planning operations. CT simulation is used to produce the same positioning of the patients in radiation therapy and also to define location of tumor. It is known that the CT images are relatively poor in soft tissue contrast. The low diagnostic quality in the cases where the soft tissue is tumoral is very important and there is a need for a supplementary method to detect tumor volume. One most useful complementary diagnostic method is magnetic resonance imaging (MRI). MRI images have high contrast of soft tissue and they are very sophisticated tools for determining the margin of tumor. Unlike CT images, each pixel of MRI images has no electron density data, and for this reason, these images (MRI images) are not used to calculate the dose in tissue and these are not applicable in this field.[16]

Image fusion is defined as the method of combining multiple images, which contains a more accurate description of the subject compared to each single image.[18-22] In image fusion, multiple image modalities are registered and combined to improve the imaging quality. With fusion of multiple modalities, the clinical applicability of medical images for diagnosis is increased.[23-25] Even image fusion can have different aims; however, its main goal is increasing the spatial resolution.[26]

According to modern treatment techniques such as image-guided radiation therapy (IGRT), it is possible to use the accurate location and shape of the tumor for each treatment session.[27] Therefore, it is essential to synchronize diagnostic methods with treatment methods to have best and most accurate treatment. This work tries to identify the practical issues for combination of CT and MRI images in real clinical cases. It also evaluates the effect of various factors on the image fusion quality.

Materials and Methods

In this study (cross-sectional, descriptive), the data of thirty patients (nonprobably consecutive sampling) with brain tumors are used for treatment planning. These patients were registered in our Radiation Therapy Department, Isfahan Milad Hospital. The tumor grade, patient's age, and gender of patients were not important in this work [Table 1]. In this study, all the image parameters and set up parameters which could have effect in image fusion process are evaluated.

Patients position

For all patients, the special head support is used to support the head during CT scan. Head supports are made by low-density material such as polyethylene foam covered with a coat of polyurethane. These materials have low-attenuation beam through process of radiotherapy. Head supports are numbered based on their standard size for various sizes of the head and neck [Figure 1]. All patients were immobilized by thermoplastic masks [Figure 2]. Thermoplastic mask is a rigid plastic sheet with about 2–3 mm thickness. This kind of mask is made from a special polymer, the melting point of which is close to 60°. Therefore, after keeping the mask in the water, it can easily be placed in the patient skin to take the shape of the head.

Computed tomography images

The CT images of patients are taken based on the patient's treatment planning according to the standard protocols of the head and neck by the Siemens SOMATOM Sensation 64 CT scanner. The general characteristics of the CT images are presented in Table 2. CT slices are taken perpendicular to the table, and by suitable head support, it has been tried to be quite axial toward patient not to be oblique.

Magnetic resonance imaging

MRI images have been taken based on the standard routine of head and neck protocols not for image fusion purposes. This is a challenge in many clinical cases. Most of MRI images are taken according to T1-weighted, T2-weighted, and T1-contrast settings.

Another issue that should be taken into account is that the MRI images are taken as "true axial" but not axial, in the other words MRI images are not taken for image fusion purposes. True axial images are defined as almost axial

Table 1: Patients characteristics (30 patients)

Characteristics	Distribution
Age (years), range	5-85
Sex (male:female)	11:19
Manufacturer (Siemens: Philips: GE medical systems)	16:10:4
Tumor grade (range)	1-4

Figure 1: Different type of numbered head support. (1, 3, and 5) With neck support. (2, 4, and 6) Without neck support. Head support provides correct and reversible position

according to the desired organ orientation so that it might have an angle with the real axial slices. In these types of images, the selected orientation of image is proper for radiologist. MRI images of the brain mostly are taken in direction from orbit to the base of the skull. On the other hand, the CT images are all axial slices of the patients; therefore, most of the slices are not aligned with MRI images in the initial form. The general characteristics of the MRI images are presented in Table 3.

Treatment planning system and image fusion

In this study, TiGRT TPS was used that uses CT images of patients for planning. In the first step of treatment planning, the CT images are imported into the software. In TPS, only the axial slices can be imported. In treatment planning process, gross tumor volume and sensitive tissues close to the tumor are contoured. After contouring, the treatment fields are designed and the energy of the treatment fields is selected according to the depth of the tumor. In the last step, the absorbed dose to for all points of the volume is calculated by computer. The quality of the treatment is evaluated using isodose curves. Isodose curve connects the points with the same dose in the irradiated volume. The hot spots and cold spots are evaluated in the patient, and the entire tumor volume should be covered by proper isodose surface.

An important application of TPS is the ability to combine various images and image fusion. This capability overlaps two different image modalities. In this way, the images of two different modalities are imported and are shown in 2D view side by side.

Image fusion can be performed in three ways which are implemented in our study. These three methods are automatic, manual, and using anatomical markers. In using anatomical markers for image fusion, three points are selected in one image and these points are also pointed in the second image. Then, the software overlays the related points in two images. In the initial evaluations, it was found that for our study, this method (anatomical markers) dose not results to proper and accurate image fusion because our set of MRI images were not taken for image fusion purposes. Therefore, the automatic and manual image fusions are selected for all data sets of this study. In automatic and manual image fusion, one reference image is selected from CT scans. Then, the related slice in MRI images is selected and the user can move the image over the reference image until the proper match is obtained. The rest of the slices are match according to position of this slice automatically. An illustration of image fusion is shown in Figure 3.

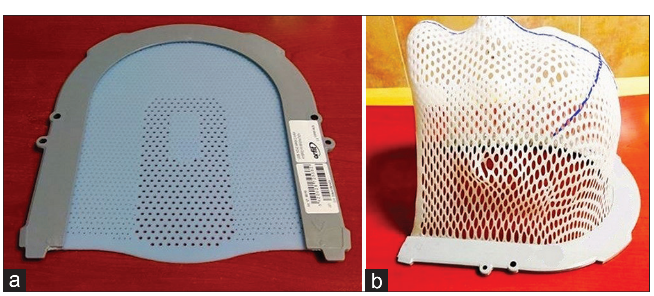

Figure 2: Thermoplastic. (a) U-shape thermoplastic before getting in water, (b) after getting in water and placing in the patient head

Results

In this study, 10% of the images of the patient were not possible to import. These 10% of the images were stored in the multi-frame format. Multi-frame image is a set of images that involves multiple images together to create a unique data set. In TPS, multi-frame images were not defined; therefore, these types of images should convert to single-frame images to import.

Ninety percent of patient's images were imported and are used in the next step. In this step, the images were used for fusion. The fused images were compared with each other to evaluate effective parameters on quality image fusion. For next steps, 27 patients were considered as the primary number of patients. The CT slice gap and MRI slice gap are illustrated in Figure 4.

Table 2: Computed tomography images parameter (30 patients)

Parameter	Value
Format	DICOM
Matrix size	512×512
Color type	Grayscale
Manufacturer	Siemens
Study description	RT^RT_head
Orientation	Axial
Slice thickness (mm)	3
Slice gap (mm)	3
kVp	120
X-ray tube current (mA)	323
Patient position	Head first-supine

Table 3: Magnetic resonance imaging images parameter (30 patients)

Parameter	Value
Format	DICOM
Matrix size	512×512
Color type	Grayscale
Manufacturer	Siemens
	Philips Medical Systems
	GE Medical Systems
Study description	Brain + generalized anxiety disorder
Slice thickness (mm)	5-6.5
Slice gap (mm)	6-8.5
Orientation	Axial
Magnetic field strength (*T*)	1-1.5
Patient position	Head first-supine

According to Figure 4, all of the MRI images had missing MRI data with respect to CT images in image fusion. Maximum and minimum amount of missing information are equal to 65% for 8.5 mm gap and 50% for 6 mm gap.

Taking MRI images with T1-weighted and T2-weighted protocols was not effective on image fusion quality because T1-weighted and other displaying characters only effect on the form of image illustration.

One of evaluated parameters in fusion process is α as it is illustrated in Figure 5. In fusion process, αCT (α reference) is constant. In primary MRI images, the deviation of head orientation is αMRI and this angle is changed to αFusion after fusion.

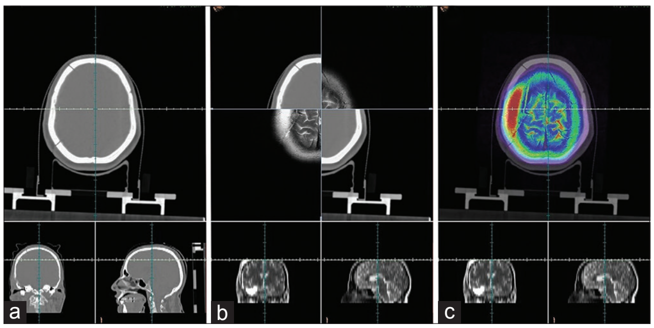

Figure 3: Illustration of image fusion. (a), computed tomography images as the fixed image in TPS software application, (b) magnetic resonance imaging images fused with computed tomography images in grid view (c), magnetic resonance imaging images fused with computed tomography images in combined view

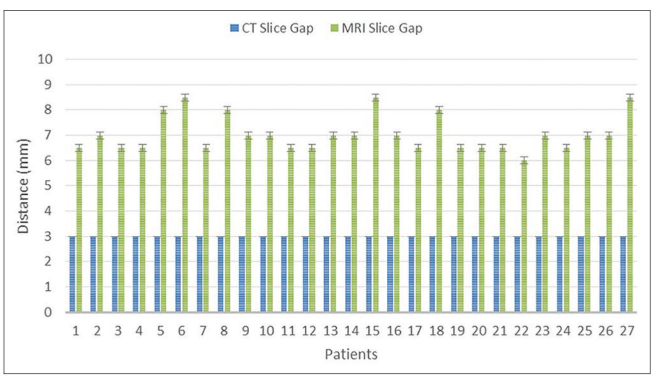

Figure 4: Computed tomography slice gap and magnetic resonance imaging slice gap in 27 patients. In some cases it is shown that magnetic resonance imaging slice gap is much larger than slice gap in computed tomography images (3 mm gap)

The accuracy of αFusion versus difference between αCT and αMRI for each patient image is illustrated in Figure 6. The accuracy of α after image fusion (αFusion) is reduced with increasing of difference between initial αCT and αMRI. On the other hand, accurate to position and orientation of head during taking MRI images, improves the accuracy of image fusion. Figure 6 shows Spearman correlation coefficient of −0.97 and significant value <0.005 (by OriginPro 8 software).

Other evaluated parameter is β. β is defined as the angle between MRI slices and CT slices in sagittal plane as illustrated in Figure 7. β represents mismatching in sagittal patient position in CT and MRI and also true axial imaging in brain MRI imaging.

The accuracy of β correction versus β for each patient image is illustrated in Figure 8. The accuracy of β is reduced with increasing of β. The Spearman correlation coefficient is equal to − 0.82 and significant value is <0.005. As it is shown, for β more than 30°, the accuracy of β is equal to 0. This means that for these angles, the image fusion was not acceptable.

Visual accuracy in our study is defined as visual evaluation of image fusion by radiologist. The visual accuracy of image fusion for each patient image is illustrated in Figure 9. In 26% of patients, visual accuracy was 0%. It means that 26% of image fusions were not approved by radiologist at all. In these images, β was more than 25°.

Total accuracy is defined as average of four parameters: existing data, accuracy of α, accuracy of β, and visual accuracy. It is illustrated in Figure 10. Maximum value of total accuracy (70.9%, patient number 24) is related to maximum value of visual accuracy. Minimum value of total accuracy (8.8%) is related to patient number 15 with maximum difference between αCT and αMRI value (11.5°) and β more than 25°.

Total accuracy of image fusion depends on β [Figure 11], difference between αCT and αMRI [Figure 12], and existing data [Figure 13, according to missing data or MRI gap], and Spearman correlation coefficient for these three

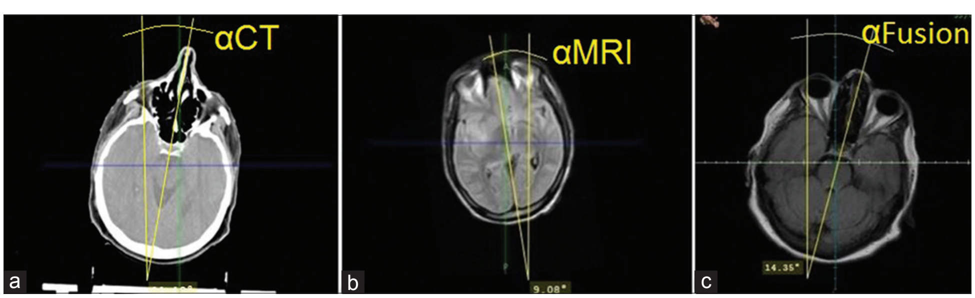

Figure 5: Illustration of α. (a) α computed tomography shows the angle between patient sagittal line and table sagittal line in computed tomography, (b) α magnetic resonance imaging shows the angle between patient sagittal line and table sagittal line in magnetic resonance imaging, (c) α fusion shows the angle between fused magnetic resonance imaging sagittal line and table sagittal line

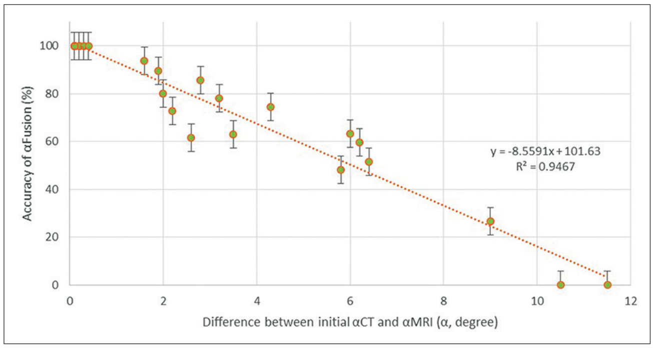

Figure 6: Accuracy of α fusion versus difference between α computed tomography and α magnetic resonance imaging

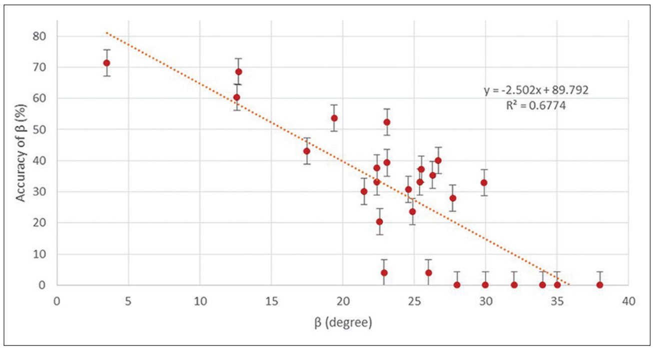

Figure 8: Accuracy of β versus β

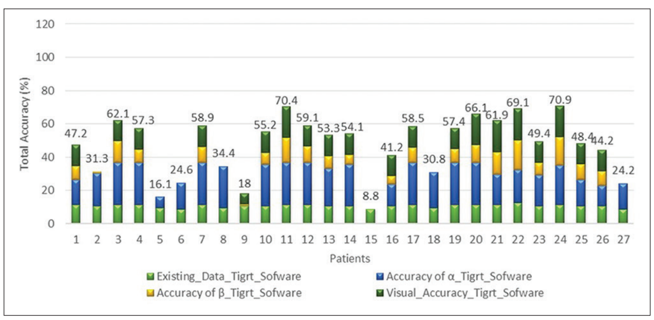

Figure 10: Total accuracy of image fusion for each patients

parameters is −0.75, −0.74, and 0.86, respectively. As it is shown, maximum coefficient is related to existing data. It means that correct choice in MRI slice gap during MRI imaging is more effective than β and difference between αCT and αMRI.

Discussion

The results showed that for successful image fusion and achieving a good precision, several parameters must be considered.

MRI should not be in the multi-frame format because this type of MRI images in the initial format is not convenient to use for image composition. Multi-frame image is one set of images to create a unique date set. In TPS, multi-frame images were not defined; therefore, these types of images should convert to single-frame images to import.

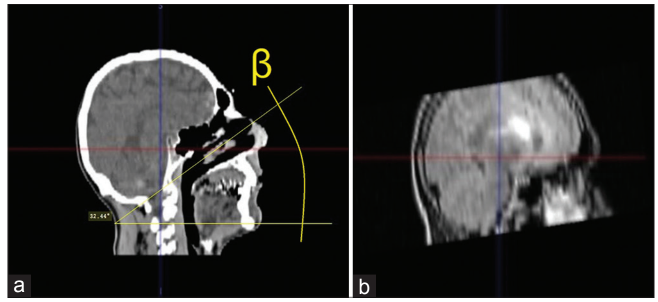

Figure 7: Illustration of β. (a), in sagittal view of computed tomography (b), in sagittal view of magnetic resonance imaging

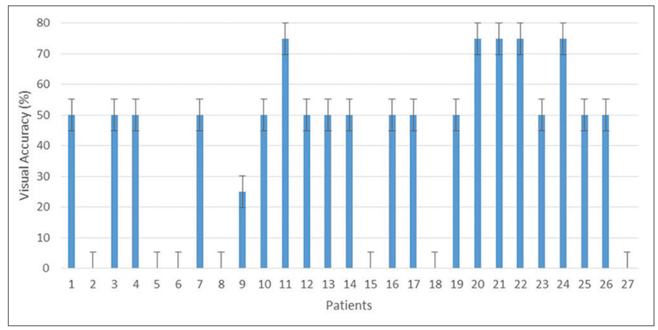

Figure 9: Visual accuracy for each patients

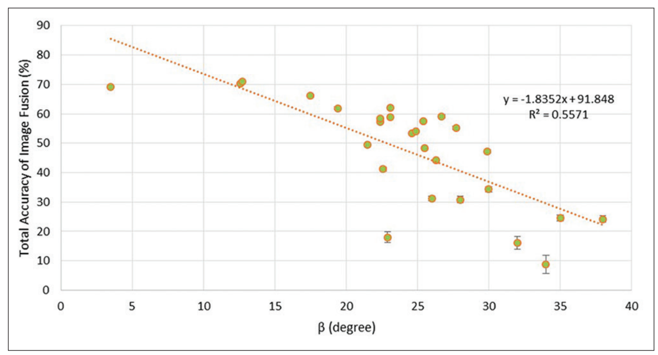

Figure 11: Total accuracy of image fusion versus β

In this study which is based on a real clinical trial for treatment planning in radiation therapy, all the MRI images of patients were taken before CT scans. This fact results in the lack of consistent positioning of the patients in the CT and MRI. The variation in patient position is defined as β and difference between αCT and αMRI. According to our data, the correct choice in β is more effective than difference between αCT and αMRI. According to visual examination, it was found that the positioning of the patients in the MRI image is more effective on image fusion. Position of patient during MRI imaging must be similar to the position of the CT. Using proper head support is one of important factors for the patient. It is recommended to use the same head support number of CT in MRI.

CT and MRI slice thickness and displaying modality (T1 and T2) for MRI are not effective on image fusion.

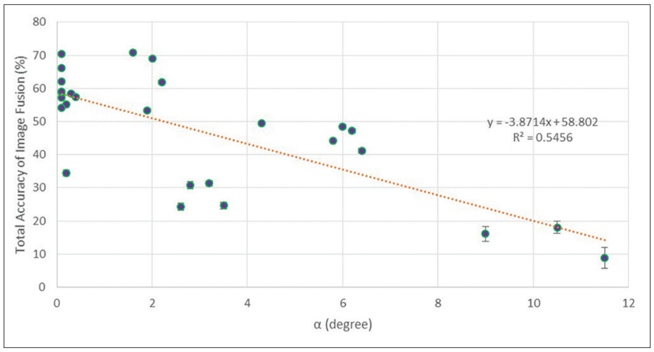

Figure 12: Total accuracy of image fusion versus difference between α computed tomography and α magnetic resonance imaging

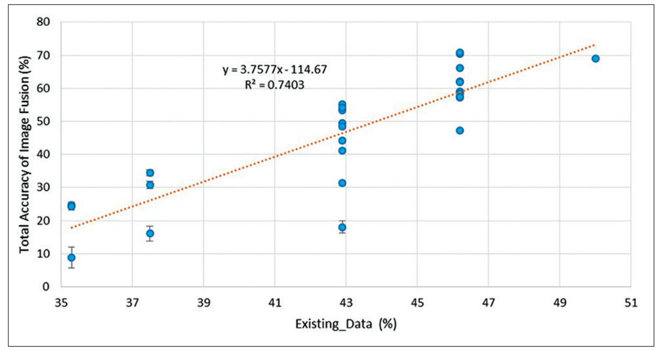

Figure 13: Total accuracy of image fusion versus existing data

The use MRI modality in which the border of skin is clearer is preferred. There is usually a missing data associated with gaps in MRI images for image fusion. MRI image must have slice gap equal to or less than CT slice gap. According to imaging of the brain, true axial CT and MRI are not efficient for image fusion. True axial MRI results mismatching of slice orientation. Taking MRI or CT images in true axial method decreases the quality of image fusion as it causes mismatching in patient position.

Although coronal and sagittal images were not importable to our treatment planning software, it is recommended to load them with other software and use them for better determination of the tumor location.

Conclusion

The most important problem in image fusion is that MRI images are taken without regard to their use in treatment planning. In general, parameters related to the patient position during MRI imaging should be chosen to be consistent with CT images of the patient in terms of location and angle. We conclude that to obtain more accurate image fusion in TiGRT TPS, there are some parameters that lead us to two methods. First method is related to MRI imaging based on CT position and other parameters after CT imaging, and second method leads us to reconstruct MRI images based on CT images.

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Conflicts of interest

There are no conflicts of interest.

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