Pol J Med Phys Eng 2010;16(2):55-66.
PL ISSN 1425-4689
doi: 10.2478/v10013-010-0006-8
website: http://www.pjmpe.waw.pl

Sajeev Thomas[1], Sampath S.[1], IndiraDevi B.[1], Bhanumathy G.[1], Sanjay S. Supe[2], Musthafa M. M.[3]

# A novel technique to evaluate the geometrical accuracy of CT-MR image fusion in Gamma Knife radiosurgery procedures*

[1]Department of Neurosurgery, NIMHANS, Bangalore, Karnataka, India
[2]Department of Radiation Physics, Kidwai Memorial Institute of Oncology, Bangalore
[3]Department of Physics, University of Calicut, Calicut, Kerala, India
**e-mail:** sajeevmthomas@gmail.com

In order to optimize the accuracy of imaging in Gamma Knife radiosurgery using the image fusion options available in the Leksell gamma plan. Phantom images from 1.5 Tesla MRI Scan (Magnetom vision – Siemens) and Computed Tomography images from Philips Brilliance 16 CT scanner were used for image fusion in Gammaplan treatment planning system . The images were fused using co-registration technique using multiview and imagemerge modules. Stereotactic coordinates were then calculated for known targets. Vector distances from the centre of the Leksell coordinate system to five known targets were measured in CT, MR and CT-MR fused images and compared with geometrical measurements. The mean values of maximum absolute errors were 0.34 mm ,0.41 mm.0.38 mm (along x-axis), 0.43 mm, 1.53 mm, 0.62 mm (along y-axis) and 0.75 mm 2.02 mm, 0.93 mm (along z-axis) for CT ,MR and CT-MR fused image data respectively. The mean error in calculating the vector distances from the center of the Leksell coordinate system (100, 100, 100) to the known target volumes are 0.22 mm, 0.8 mm and 0.43 mm for CT, MR and CT-MR fused images, respectively. Image fusion functions available in gamma plan are useful for combining the features of CT and MR imaging modalities. These methods are highly useful in clinical situations where the error associated with Magnetic Resonance Imaging is beyond acceptable levels.

**Key words:** image fusion, magnetic resonance imaging, gamma knife radiosurgery, computed tomography.

* Note: This work was partly presented in the form of abstract in the proceedings at the International Leksell society Meeting 2010, Athens, Greece, May 16-20, 2010.

## Introduction

In gamma knife Radiosurgery a patient with head frame attached to his skull undergoes Magnetic Resonance Imaging, Computed tomography (CT) scanning and Digital Subtraction Angiography procedures for tumor localization [6, 15]. Image fusion combines the features of multiple imaging systems and provides better image information required for stereotactic localization.

The choice of the imaging system is based on the characteristics of the individual radiosurgical lesion [5]. Many authors reported the superior geometric accuracy of the computerized tomography systems compared to Magnetic Resonance Imaging systems [2, 8, 16-17], however, concerns regarding the z-axis efficiency of Computed Tomography systems [16] have been reported. In contrast, Magnetic Resonance imaging systems offer superior contrast resolution compared to computerized tomography [9-16].

Image fusion is a technique that combines the complementary information from separate imaging studies into single coherent study and allow simultaneous visualization of each imaging modality using a variety of display techniques [2, 5]. In general, the fusion may be multimodal or monomodal [10] and it may be performed using hardware-based or software-based [10, 15] approaches. Image fusion methods are based either on detection of geometric features as points and lines or with iconic method based on the voxel property [1].

Popular image fusion techniques are based on fiducial markers or on surface matching of volumes identified on each modality. The fiducial marker technique requires markers visible on all modalities, but such markers reduce the precision of fusion. The chamfer match technique is based on sets of points belonging to the same anatomical structures and visible in each study [9]. In this study, the term image fusion represents multimodal fusion [10], as image fusion studies were performed on images from Computed Tomography and Magnetic Resonance Imaging systems.

Leksell Gamma plan has two options for combining the features of imaging modalities, known as image fusion and co-registration. In image fusion, the images can be used for two defined studies so that anatomical structures can be visualized by enhancing the best features of both studies. This is done by setting maximum and minimum grey scale values, by mixing the studies or subtracting the characteristics of one study from other. The two studies are denoted here as first study and second study.

Coregistration technique uses an iterative method based on a metric (scalar value) that represents the amount of common information between the reference and the image study to co-register. The process starts with an initial transformation that, given an arbitrary position in the reference study, computes the corresponding position in the image study to co-register. Giving the initial transformation, the co registration algorithm computes a metric value by looking at the intensity at a great number of positions in the reference study and intensity at the corresponding position in the image study to co-register. This calculation is performed for a large number of different transformations, in order to find the optimal match between two studies. Co-registration uses a global optimizer to try different transformations to maximize the metric value.

Some studies have been reported concerning the measurement of image fusion quality using mutual information correlation function [3, 10]. It is done as a plot of intensity of all pixels from one image versus another [10], however, mutual information does not recognize the anatomy or physiology of the underlying body tissues or organs.

To make this tool clinically useful the accuracy, robustness, speed and autonomy have to be verified. The present study is aimed at evaluation of accuracy of the image fusion using co-registration provided with multiview and imagemerge modules of Gammmaplan 5.34. In this study we have used different image data sets with larger FOV and different voxel sizes to simulate maximum probability of errors in a standard clinical setup.

## Methods

An octagonal perpex phantom (Figure 1) that could be secured to the base of the Leksell frame (Elekta AB, Stockholm, Sweden) was designed (Figure 1). Holes of 1.5 mm diameter and with length varying from 30 mm to 110 mm were accurately drilled and filled with copper sulphate solution for contrast resolution. The holes were spaced at 10 mm distances. Five volume chambers of 1 cubic centimeter were filled with copper sulphate solution for MR imaging and with Teflon rods for CT-imaging. The phantom has additional provisions for keeping films, ion chambers and diods for future investigations. The plates are connected using a polythene rod and tightened with perpex bolts.


**Figure 1.** Photograph of phantom used for evaluating error in MR-imaging and Computed Tomography Imaging

**Table 1.** Sequence parameters used for the phantom stereotactic imaging in the Siemens Magnetom Vision MRI 1.5 T Unit

| | |
|---|---|
| Field of View | 250 × 250 |
| Matrix | 256 × 256 |
| Voxel size | 0.98 × 0.98 × 1 mm |
| Slice thickness | 1 mm |
| Slice interval | 0 mm |
| Flip angle | 12 degrees |
| TE | 4 ms |
| TR | 9.3 ms |
| Scan Time | 8 min 21 sec |
| Swap phase Encoding | left to right |

The phantom was attached to the Leksell frame along with respective indicator boxes which were attached to the MR and CT adapters for Siemens 1.5 Tesla (Magnetom vision) and Philips Brilliance 16 CT scanner. Images were acquired using the T1-Weighted MP RAGE sequence in Siemens Magnetom Vision 1.5 Tesla MRI (Table 1) and using Helical acquisitions after inserting guide wires of 0.5 mm sealed in capillary tubes in computed Tomography unit (Table 2).

**Table 2.** Parameters used for the acquisition of phantom CT images in Philips Brilliance 16 CT Unit

| | |
|---|---|
| Field of View | 300 × 300 |
| Slice Thickness | 1 mm |
| Voxel Size | 0.59 × 0.59 × 1 mm |
| Acquisition | Helical |
| Matrix | 512 × 512 |
| Gantry Tilt | 0 degrees |
| Increment | 1 mm |
| Slice interval | 0 mm |
| CT DI | 40.3 mGy |

Images were exported to the Leksell Gamma plan through the hospital network. The images were defined and registered in the Leksell Gamma plan (version 5.34) and then, the stereotactic coordinates of the holes (Figure 2) were determined in each image sets.

Image fusion was performed in Gamma plan using CT as the reference image (first image set for maximum CT values). The coordinates of the geometrically known targets were calculated using CT, MR, and CT-MR fused image sets separately. Distances from the centre of the Leksell Coordinate system (100, 100, 100) to the volume chambers located at different corners (Anterior, Posterior, Right, Left) and in the middle were estimated in all image data sets and compared with geometrical values.

These studies were repeated 12 times over a period of 12 days and the measurements were independently verified by two medical physicists. The maximum errors were determined by calculating the differences between geometrically known values and the stereotactic values calculated by Leksell Gammaplan.

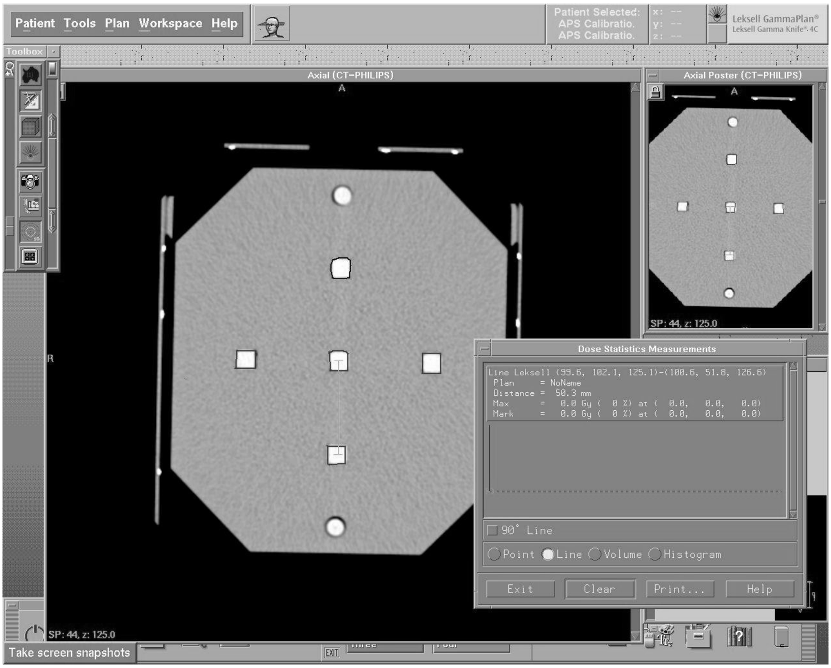


**Figure 2.** Evaluation of Vector Distances from the center of the Leksell coordinate system (100, 100, 100) to Known Targets using Leksell Gamma plan

## Results

The mean values of maximum error in stereotactic coordinates calculation were 0.38 mm, 0.62mm, 0.93 mm along x, y and z-axis when the CT-MR image fusion was applied with CT as the reference image. The mean of maximum error in estimation of the vector distances from the centre of the coordinate system to the known targets was 0.43 mm in fused images. The obtained errors are represented as scatter graphs in Figure 3.

The mean value of maximum errors along x-axis was equal to 0.34 mm and 0.41 mm, respectively, when CT images and MR images were used. Mean maximum error along y-axis was 0.43 mm when CT images were used and 1.53 mm with MR images and along z-axis it was 0.75 mm using CT images and 2.02 mm using MR images.

The mean maximum errors of the calculated vector distances from the centre of the coordinate system to the volume chambers (Known Targets) using CT and MR images were equal to 0.22 mm, 0.80 mm and they were reduced to 0.43 mm using the image fusion.

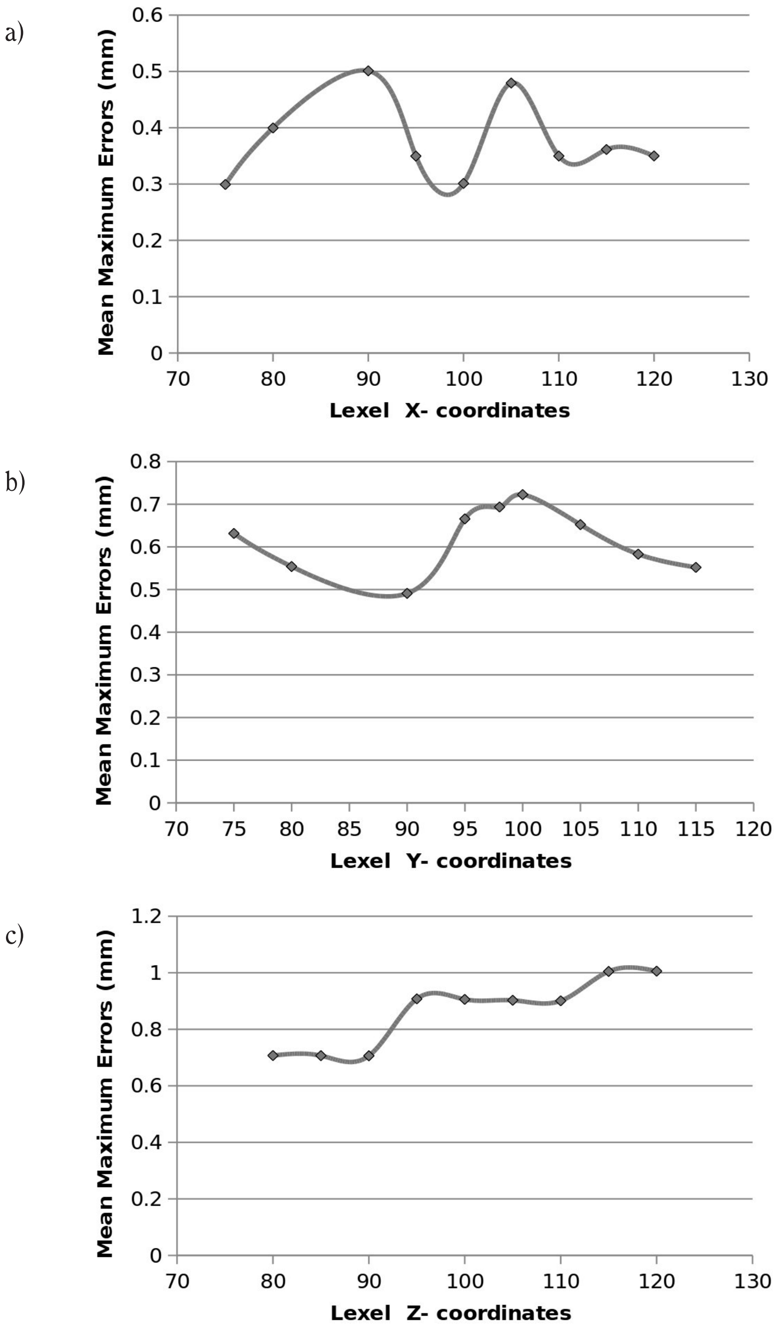


**Figure 3.** Line graph for mean maximum error estimated along: a) x-axis, b) y-axis, c) z-axis (CT-MR fused Images)

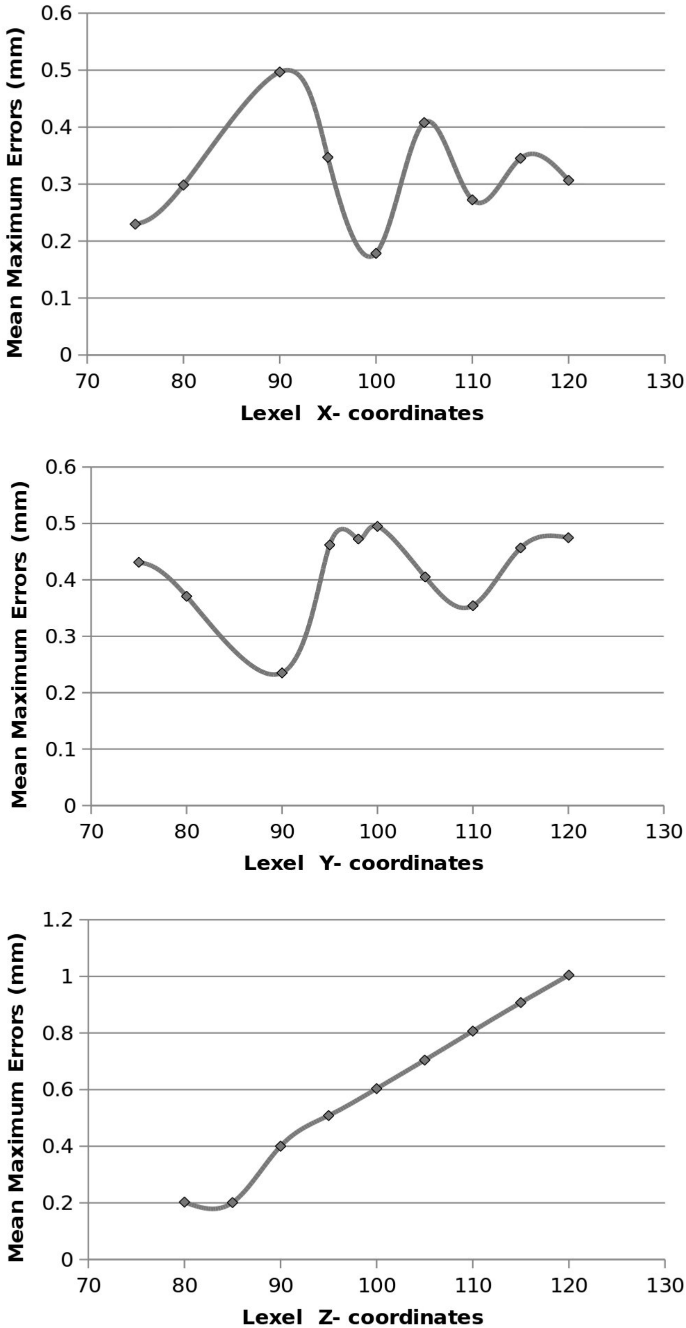


**Figure 4.** Line graph for mean maximum error estimated along: a) x-axis, b) y-axis, c) z-axis (CT-Images)

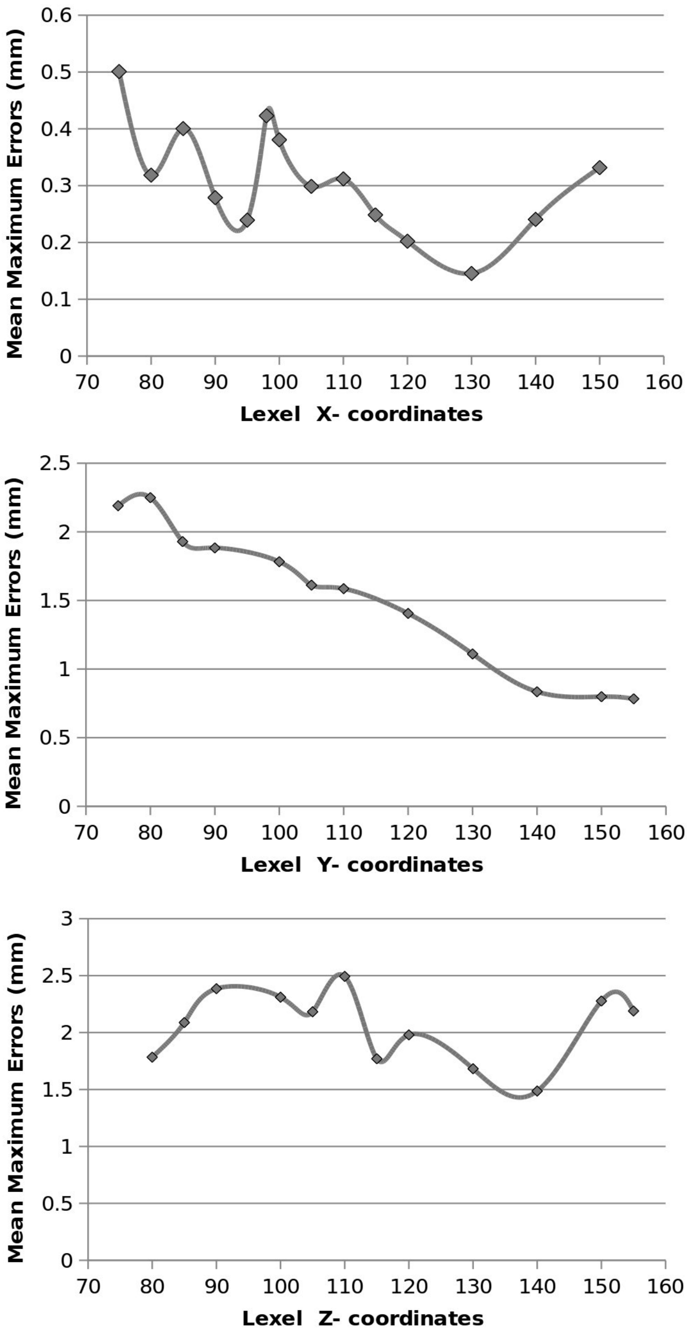


**Figure 5.** Line graph for mean maximum error estimated along: a) x-axis, b) y-axis, c) z-axis (MR Images)

## Discussion

A distortion of MR imaging is an important factor that limits the spatial accuracy of Gamma knife Radiosurgery. However, the superior contrast resolution and multiplanar imaging capability position the MR as the best modality for neuro imaging. On the other hand, Computed Tomography systems provide precise geometric localization with minimum contrast resolution. In this study the geometric accuracy of CT images was within 1 mm in all three (x, y, z) directions, while it exceeded 1 mm in MR imaging.

After image fusion the mean values of maximum errors were reduced to less than 1 mm in all directions which is the desired accuracy for stereotactic radiosurgery imaging. Maximum error observed in z-direction may be due to the maximum dimension of voxel in that direction compared to x-axis and y-axis directions.

Image fusion mixes the image details of two defined studies in the stereotactic space and provides better visualization. The image fusion software uses mathematical algorithms and statistical techniques that operate independent of the imaging modalities to align the image datasets [10]. One of the datasets can be transformed through translation, rotation and deformation to give maximum overlap of common regions.

In gamma plan 5.34 version, the image co registration is provided with Multiview and Image Merge modules. In LGP software a Normalized Mutual Information (NMI) algorithm is used for image co-registration [1, 4] where non-defined image sets may be used. Detailed comparison of these options are beyond of the scope of this work, which was devoted to verification of the image fusion option available in Leksell Gamma plan system.

The estimated reduction of the error in calculating the vector distances from the centre of stereotactic coordinate space to 5 known targets is a clear indicator for better stereotactic accuracy obtained through CT-MR image fusion. The study revealed that the errors after performing CT-MR fusion were slightly higher than the error of the images with minimum error and lower than the error of image data set with maximum error.

The study showed the minimal error along x axis and significant improvement in accuracy along y and z axes compared to the MR images alone. The voxel dimensions of the reference CT images of (0.59 mm × 0.59mm × 1mm) were different from the voxel dimensions of MR images (0.98 mm × 0.98 mm × 1 mm) used in this study. Such dimensions were chosen in order to evaluate the maximum error for conditions of an ordinary clinical arrangement, where equal imaging parameters cannot be selected. The observed maximum error along z-axis is partly due to the maximum dimension of the voxels in z-direction. Even considering the larger field of view and taking into account other imaging parameters, the error in estimating the stereotactic coordinates was less than 1 mm for fused image data.

## Conclusion

The study showed that the accuracy of fused CT-MR images was better than the accuracy of MR images alone. Image fusion technique combines the complementary information from all imaging equipment and is a useful tool for improving the geometrical accuracy of Gamma knife radiosurgery procedures. The accuracy of image fusion procedure depends on the quality of the individual image data sets and on the amount of information used from each image data set. Hence, this method should be used only after verifying the stereotactic accuracy of the individual image sets used for fusion.

## References

[1] Isambert A, Bonniaud G, Lavielle F, Malandain G, Lefkopoulos D et al. A phantom study of CT, MR and PET image registrations with block matching based algorithm. Cancer Radiother. 2008 Dec;12(8):800-808.

[2] Kessler ML. Image registration and data fusion in radiation therapy. Br J Radiol. 2006;79(Spec 1):S99-108.

[3] Kim J, Hammoud, Yin F, Zhao Y, Kim J, Movsas B. Comparisions of six similarity measures functions for intensity based 3D/2D image fusion. Radiat Oncol Biol Phys. 2005 Oct;63(Suppl 2):S140.

[4] Kniesely JP, Bond JE, Yue NJ, Studholme C, Lotbiniere AC. Image registration and calculation of a biologically effective dose for multisession radiosurgical treatments. Technical note. J Neurosurg. 2000 Dec;93(Suppl 3):208-218.

[5] Kooy HM, van Herk M, Barnes PD, Alexander E 3rd, Dunbar SF, Tarbel NJ et al. Image fusion for stereotactic radiotherapy and radiosurgery treatment planning. Int J Radiat Oncol Biol Phys. 1994 Mar 30;28(5):1229-1234.

[6] Leksell L, Lindquist C, Adler JR, Leksell D, Jernberg B, Steiner L. A new fixation device for the Leksell stereotaxic system. Technical note. J Neurosurg. 1987 Apr;66(4):626-629.

[7] Mack A, Mack G, Scheib S, Czempiel H, Kreiner HJ, Lomax NJ et al. Quality assurance in stereotactic radiosurgery/radiotherapy according to DIN 6875-1. Stereotact Funct Neurosurg. 2004;82(5-6):235-243.

[8] Mongiog V, Brusa A, Loi G, Pignoli E, Gramaglia A, Scorsetti M et al. Accuracy evaluation of fusion of CT, MR, and spect images using commercially available software packages (SRS PLATO and IFS). Int J Radiat Oncol Biol Phys. 1999 Jan;43(1):227-234.

[9] Novotny J Jr, Vymazal J, Novotny J, Tlachacova D, Schmitt M, Chuda P et al. Does new magnetic resonance imaging technology provide better geometrical accuracy during stereotactic imaging? J Neurosurg. 2005 Jan;102(Suppl):8-13.

[10] Saw.B.Cheng, Chenn Hungcheng, Beatty, E Ron, Wagner Henry: Multimodality image fusion and planning and dose delivery for radiation therapy. Med Dosim. 2008 Summer;33(2):149-155.

[11] Shad LS, Lott S, Schmitt F, SturmV, Lorenz WJ. Correction of spatial distortion in MR imaging: a prerequisite for accurate stereotaxy. J Comput Assist Tomogr. 1987 May-Jun;11(3):499-505.

[12] Sharpe M, Brock KK. Quality assurance of serial 3D image registration, fusion, and segmentation. Int J Radiat Oncol Biol Phys. 2008;71(1 Suppl):S33-37.

[13] Studholme C, Hill DLG, Hawkes DJ. An overlap invariant entropy measure of 3D medical image alignment. Pattern Recognit 1999 Jan;32(1):71-86.

[14] Watanbe Y, Han E. Image registration accuracy of Gammaplan: a phantom study. J Neurosurg. 2008 Dec;109(Suppl):21-24.

[15] Wu A, Lindner G, Maitz AH, Kalend AM, Lunsford LD, Flickingert JC et al. Physics of Gamma knife Approach on convergent beams in Stereotactic Radiosurgery. Int J Radiat Oncol Biol Phys. 1990 Apr;18(4):941-949.

[16] Yu C, Petrovich Z, Appuzzo MLJ. An image fusion study of the geometric accuracy of Magnetic Resonance imaging with Leksell Stereotactic Localisation system. J Appl Med Phys. 2001 Winter;2(1):42-50.

[17] Yu Cheng, Apuzzo MLJ, Zee Chi-Shing, Petrovich Z. A phantom study of the geometric Accuracy of Computed Tomography and Magnetic Resonance Imaging Streotactic Localisation with Leksell Stereotactic system. Neurosurg. 2001 May; 48(5):1092-1099.