Towards a Second Brain Images of Tumours for Evaluation (BITE2) Database

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Abstract. One of the main challenges facing members of the medical imaging community is the lack of real clinical cases and ground truth datasets with which to validate new registration, segmentation, and other image processing algorithms. In this work we present a collection of data from tumour patients acquired at the Montreal Neurological Institute and Hospital that will be released as a publicly available dataset to the image processing community. The database is comprised of 9 patient data sets, in its initial release, that consist of a preoperative and postoperative, gadolinium enhanced T1w MRI, pre- and post- resection tracked intra-operative ultrasound slices and volumes, expert tumour segmentations following the BRATS benchmark, and intra-operative ultrasound with/and MRI registration validation target points. This database extends the already widely used BITE database by improving the quality of registration validation and the variety of data being made available. By including addition features such as expert tumour segmentations, the database will appeal to a broader spectrum of image processing researchers and be useful for validating a wider range of techniques for image-guided neurosurgery.

Keywords: Database · Validation · Medical imaging · Intra-operative ultrasound

1 Introduction

Within the medical image processing community, one of the greatest challenges associated with the development of a new algorithm, be it for registration or segmentation, lies in the ability to validate the new method on real clinical data to demonstrate its superiority over existing methods and its applicability for clinical tasks. This challenge is amplified by the fact that technical laboratories are rarely located within a clinical environment making the access to appropriate validation data even more cumbersome. In addition, it is often difficult to find clinical experts who have the time to provide expertise in terms of creating a gold standard for validation purposes. A solution to some of these challenges lies in the creation of publicly available data sets that can be used by members of the medical image processing community for validation of new techniques that incorporate real clinical data. The data sets should be comprehensive in terms

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of modalities available, and offer data for validation of registration and segmentation. Over the last several years, imaging data for 25 patients undergoing neurosurgery for brain tumours has been collected at the Montreal Neurological Institute and Hospital. In this abstract we present 9 of these 25 cases that will be included in a publicly available database for use by the medical image processing community. Each patient underwent neurosurgery for a brain tumour and each patient included contains a pre- and post-operative T2 and T1 weighted, gadolinium enhanced MRIs, tracked intra-operative ultrasound (iUS) volumes and 2D slices, expert tumour segmentations following the BRATS [1] benchmark, and MRI-iUS registration validation target point sets. The work is an extension to the original Brain Images of Tumours for Evaluation (BITE) [2] database that has seen extensive use in the medical image processing literature and aims to improve on some of its critiques as described in other published work using the data for evaluation.

2 Methods

The patient information is summarized in Table 1. All patients consented to participate in the study and agreed to have their anonymized clinical data made publicly available. The complete study included 10 males and 15 females of which 3 and 6, respectively, are presented here. The mean age was 64. Both primary and metastatic brain tumours were included in the imaging study. All tumours included in the study were supratentorial and varied amongst brain lobes.

Table 1. Patient information

Patient	Sex	Age	Tumour type	Lobe
1	F	72	Metastases	L–O/P
2	F	68	Glioblastoma	L–T
3	M	53	Glioblastoma	L–T/P
4	F	84	Glioma	R–P
5	F	41	Meningioma	L–F
6	M	63	Meningioma	R–F
7	F	77	Meningioma	R–F
8	F	62	Meningioma	L–O/P
9	M	55	Glioma	R–F

2.1 MR Images and Processing

Each patient in the series had a gadolinium enhanced 1.0 mm isotropic T1 weighted MRI, obtained on a 1.5 T MRI scanner (Ingenia Phillips Medical Systems). All images were processed in a custom image processing pipeline as follows [3]. First, the MRI is denoised, after estimating the standard deviation of the MRI Rician noise [4]. Next, intensity non-uniformity correction and normalization is done by estimating the non-uniformity field [5], followed by histogram matching with a reference image to normalize the intensities. The preoperative images were acquired on average 7 days

prior to surgery. When available, T2w and FLAIR images were also included for the patient dataset, however the acquisition of these modalities was dependent on surgical need and not always included. Postoperative MR images were also T1w and were acquired within 48 h after surgery, however, slice thickness varied depending on the diagnostic request of the surgeon for the patient. All MR images were converted into the MINC format used at the McConnell Brain Imaging Centre, Montreal Neurological Institute and Hospital. All MINC tools can be found at packages.bic.mni.mcgill.ca and are publicly available.

2.2 Tracked Intraoperative Ultrasound

In each of the cases included in the database, tracked intraoperative ultrasound was acquired as part of a protocol for brain shift investigation [6]. Intraoperative ultrasound was acquired using our custom built prototype neuronavigation system, IBIS [7]. The workstation is equipped with an Intel Core i7-3820 @ 360 GHz x8 processor with 32 GB RAM, a GeForce GTX 670 graphics card and Conexant cx23800 video capture card. Tracking is performed using a Polaris N4 infrared optical system (Northern Digital, Waterloo, Canada). The Polaris infrared camera uses stereo triangulation to locate the passive reflective spheres on both the reference and pointing tools with an accuracy of 0.5 mm [8]. The ultrasound scanner, an HDI 5000 (ATL/Philips, Bothell, WA, USA) equipped with a 2D P7-4 MHz phased array transducer, enables intraoperative imaging during the surgical intervention. The ultrasound system transmits images using an S-video cable to the workstation at 30 frames/second and the ultrasound transducer probe is outfitted with a spatial tracking device with attached passive reflective spheres (Fig. 1) (Traxtal Technologies Inc., Toronto, Canada) and are tracked in the surgical environment.

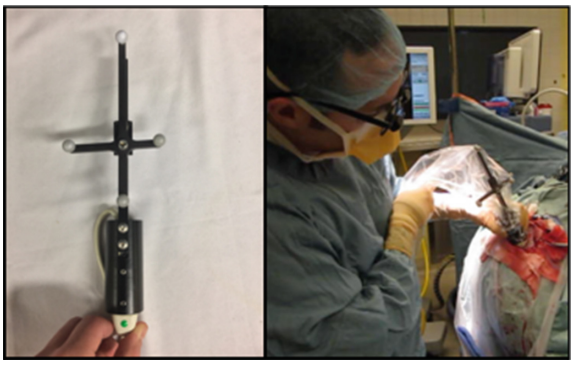

Fig. 1. Ultrasound probe with fitted tracking device (left) and use intraoperatively during neurosurgery (right).

For each case the surgeon acquired freehand ultrasound images in sweeps of 400 to 1000 2D images, moving the probe continuously in the plane of the craniotomy in a continuous forward motion in order to minimize any errors due to calibration. The sets

of iUS series included in this database involved ultrasound images acquired at two time points during surgery: before and after resection. Pre-resection ultrasound images were acquired on the intact dura of the patient and post-resection ultrasound was acquired either in the resection cavity or on a dural graft attached to the patient after the resection was completed. During post-resection acquisition the cavity was filled with saline solution. For use in a volume-to-volume registration scheme the iUS series were reconstructed with a GPU implementation that looks for US pixels within a given search radius and that are no farther than 1.0 mm away from the point of interest. Each US voxel is weighted with a Gaussian function and normalized after all US pixels have been accumulated [9]. Both the original 2D series and the reconstructed volumes are available in the database. The tracking information for the individual slices is self-contained within the header of the ultrasound images which are also in the MINC format. An example of the included 2D and 3D iUS data can be seen in Fig. 2.

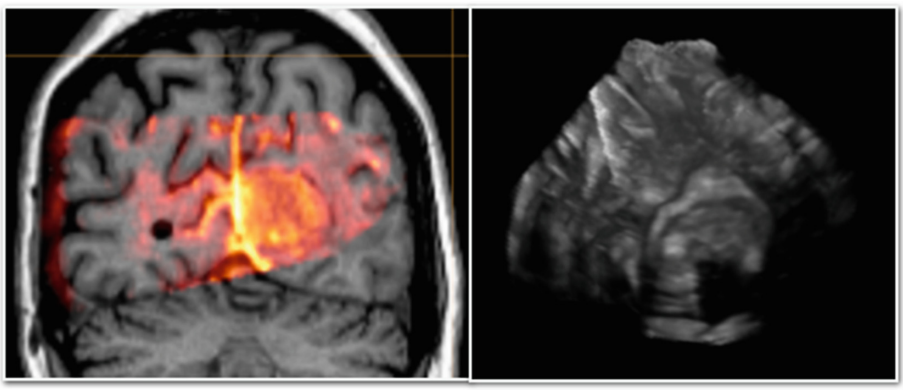

Fig. 2. Left: Example of a 2D US slice (orange) overlaid on the corresponding MR slice (grey) after registration. Right: 3D reconstructed volume of the iUS series. (Color figure online)

2.3 Tumour Segmentation

All tumour segmentations were performed by a senior neurosurgical resident (C. C.) using ITK Snap and followed the BRATS benchmark [1] in hopes of keeping consistent with a widely used system within the image processing community. For cases with gliomas, the labels included: (i) T2 tumour hyperintensities (edema), (ii) enhancing tumour core, and (iii) non-enhancing tumour core. For the other non-glioma tumour cases, all of these structures that were visible were segmented. An example of a segmentation for a glioblastoma and a meningioma can be seen in Fig. 3. The average solid tumour volume for the 9 cases was 28 cm^3. The intra-rater variability for the segmentations was measured by comparing two segmentations of the same tumour done on different days for both a glioblastoma and a meningioma. The intraclass correlations (ICC) for the solid tumour volume was 0.91 and 0.96 respectively for the Glioblastoma and meningioma cases, showing a consistent segmentation by the expert rater.

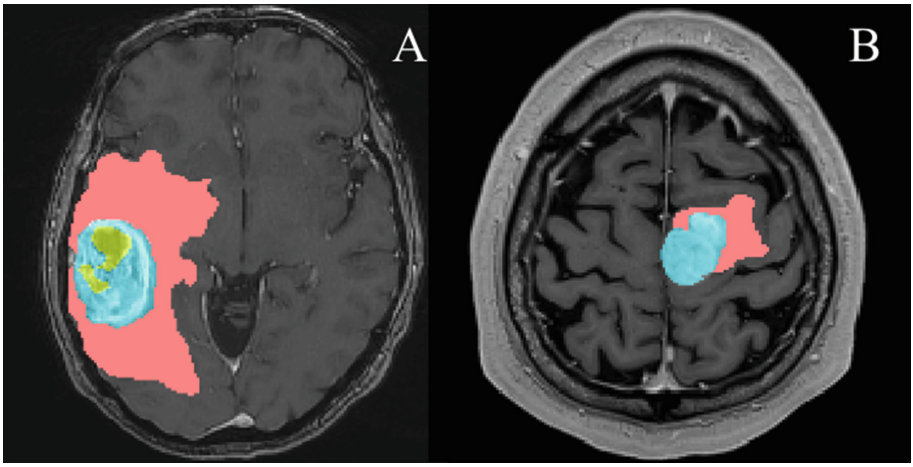

Fig. 3. Examples of expert segmentations that will be provided in the database of a GBM (A) and meningioma (B). In each segmentation, the same colour is used to differentiate between Edema (red), Enhancing tumour core (blue), and non-enhancing tumour core (green). (Color figure online)

2.4 Registration and Registration Validation

Since the intent of this database is to be useful to a broad image processing community both linear and non-linear registration transforms for the preoperative MRI and iUS data are included in the database.

Registration techniques to correct for brain shift have recently been developed, based on gradient orientation alignment, in order to reduce the effect of the non-homogeneous intensity response found in iUS images [9]. Once an iUS volume has been reconstructed the two volumes are registered using an algorithm based on gradient orientation alignment [9] which focuses on maximizing gradients with minimal uncertainty of the orientation estimates (i.e. locations with high gradient magnitude) within the set of images. This can be described mathematically as:

$$T^* = \arg\max_T \sum\nolimits_{x\in\Omega} \cos(\Delta\theta)^2 \tag{1}$$

where T* is the transformation being determined, Ω is the overlap domain and $\Delta\theta$ is the inner angle between the fixed image gradient, ∇I_f, and the transformed moving image gradient $\mathrm{J}^T \cdot \nabla I_m$:

$$\Delta\theta =< (\nabla I_f, \mathrm{J}^T \cdot \nabla I_m) \tag{2}$$

The database includes the registration transforms obtained using this method.

Validation target sets for the MR-iUS registrations were obtained using the Validation Grid tool [10]. The tool is based on manually registering two images through manipulation of a series of target points that are placed as a regular shaped grid on both

the target and fixed image. As the points are moved on the target image, the registration transform is updated based on the displacement of corresponding (target and fixed) grid points using a thin plate spline model. Due to the difficult nature of manually aligning images of different modalities the size of the validation grid can be changed from a coarse $2 \times 2 \times 2$ grid to a finer $7 \times 7 \times 7$ grid allowing the user to manually register the images in a hierarchical fashion from the largest deformations to small and local ones. Once complete, the set of points is exported and can be used as a large set to validate different registration procedures. A visual representation of this procedure can be seen in Fig. 4.

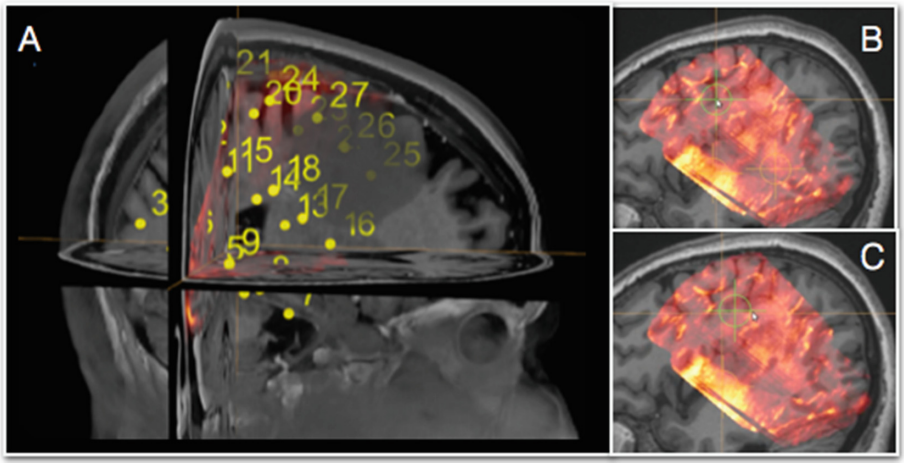

Fig. 4. Example of Validation Grid use for patient 9. A: 3D view of validation grid (yellow dots) on top of MRI volume (grey) and iUS volume (orange). B/C: 2D slice of unregistered iUS-MRI (B) and a target point (green) near a mis-registered sulcus being manipulated to facilitate registration (C). (Color figure online)

3 Discussion and Conclusion

We've presented here the structure and initial work towards a comprehensive tumour image database complete with multimodality imaging, intraoperative imaging, expert segmentation labels, linear and non-linear registration transformations, and registration validation target point sets with the goal of releasing 9 of the 25 patient sets publicly. The large range of data will enable comparison of a multitude of image processing techniques with a standard set of data for comparison with other techniques in the literature based on real clinical data.

The work here demonstrates an expansion on a previously popular brain tumour database [2] that has seen extensively used for validation in the literature. By adding a more reliable validation metric and through the introduction of expert segmentations following the BRATS benchmark it can be extended to both the registration and segmentation image processing communities. With further development and completion

of the database we hope to inspire multiple future studies that will eventually benefit brain tumour patients through an easy and efficient resource to validate state-of-the-art image processing technologies. This will translate into tools and techniques that allow surgeons to better visualize tumours before, during, and after surgical interventions.

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