MR Imaging in Radiosurgery for Trigeminal Neuralgia

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Abstract

The hallmarks of radiosurgery for trigeminal neuralgia are high radiation doses, very small target volume, and close proximity to critical organs. This kind of treatment requires maximum precision in definition of all the anatomical structures. Although dose distribution is calculated with computed tomography, this modality alone cannot show specific anatomical volumes with sufficient precision. These discrete structures are clearly visible on various magnetic resonance imaging sequences. The highest possible accuracy of registration of CT images and specific MR sequences is vital. Our institutional protocol for all patients with intracranial lesions includes T1-weighted 3D MPRAGE without and with contrast enhancement. For trigeminal neuralgia cases, a CISS sequence is also routinely used. Thanks to its high-resolution imaging, the CISS sequence allows for accurate delineation of the target volume – the fifth cranial nerve – and organs at risk surrounding the target, including cranial nerves and the structures of the inner ear.

1 Patient examination position with head in Head/Neck 20 coil.

The Treatment Planning Department in the Maria Sklodowska-Curie National Research Institute of Oncology, Gliwice Branch, has been equipped with a 1.5T MAGNETOM Aera (Siemens Healthcare, Erlangen, Germany) since 2012. An on-site scanner is needed because MRI is used as a standard in both conventional radiotherapy and radiosurgical techniques. According to target volume type and location, various imaging sequences are routinely used.

Ionizing radiation has been successfully used for years in the treatment of trigeminal neuralgia. This method enables noninvasive treatment of severe facial pain using a high dose of radiation. With the Leksell Gamma Knife (Elekta AB, Stockholm, Sweden), high dose means 80–90 Gy in a single fraction specified at dose maximum. With the CyberKnife (Accuray, Sunnyvale, CA, USA), it means 60 Gy in a single fraction specified at the isodose encompassing the target volume [1–4]. High radiation doses, very small target volumes and close proximity to critical organs require definition of all the anatomical structures with the highest precision. With the CyberKnife system, the treatment planning calculation is performed with computed tomography (CT) data on electron density. However, CT imaging alone does not allow for differentiation of specific anatomical volumes, whereas these discrete structures are clearly visible on various MR sequences.

The accurate registration (also called fusion) of the planning CT and given MR sequence is vital. Registration in radiotherapy is a process of visualization and alignment of multimodal images [5, 6].

In our Institute, rigid registration is the standard method of handling diagnostic images used for radiotherapy planning. In case of trigeminal neuralgia, two different fusions are commonly used.

The concepts and information presented in this paper are based on research and are not commercially available.

Technical aspects of CT and MR scanning

Our routine practice is CT imaging in immobilization system with head mask. The CT scans are acquired from the top of the mask to the subclavian area. The CT image matrix resolution is 512 x 512 pixels with 1.0 mm gap between slices and 50 cm FOV acquired with 120 kV and 500 mAs. A flat scanner couch overlay is used for CT imaging to maintain the same position of the body as on the treatment couch.

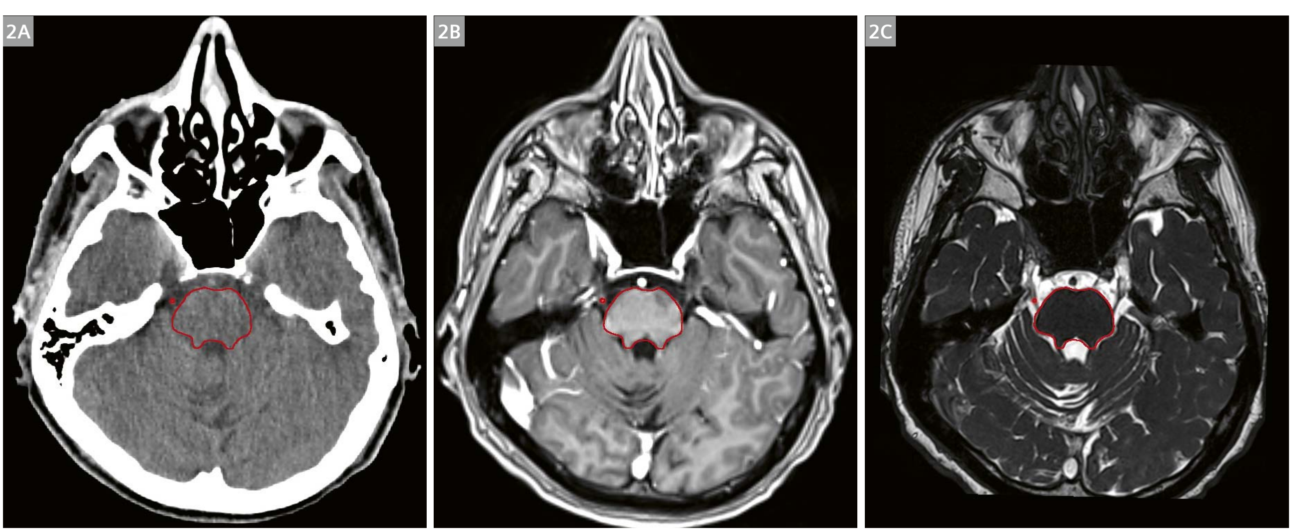
The protocol for all patients with intracranial lesions includes T1-weighted 3D Magnetization Prepared Rapid Acquisition Gradient Echo (3D MPRAGE) without and with contrast enhancement. Moreover, for trigeminal neuralgia cases, a Constructive Interference in Steady State (CISS) sequence is routinely used [7–9]. This is a heavily T2-weighted fast gradient echo sequence of 0.35 mm spatial resolution. It allows for precise visualization of minute neural structures, especially the trigeminal nerve root where the target volume is located. Usually, one of two possible target volume locations is used. One is the root entry zone, close to the brainstem, allowing for excellent pain control [10], but irradiating this region is believed to be associated with higher rates of adverse effect, including facial hypoesthesia and anesthesia dolorosa. The second is the retrogasserian region (zona triangularis), which is more distant from the brainstem, and therefore thought to be safer to irradiate. The CISS sequence allows for accurate delineation of the target volume thanks to imaging with high resolution and great detail of the fifth cranial nerve against the background of bright cerebrospinal fluid. Moreover, it allows for accurate differentiation between nerve fibers and neighboring vessels, which are often the cause of trigeminal neuralgia due to neurovascular conflict. Finally, it precisely reveals organs at risk surrounding the region of interest, including cranial nerves and the structures of the inner ear (cochlea and semicircular canals) [7]. To better identify vascular structures, especially if the cerebellopontine region has atypical anatomy, vascular sequences such as TOF (Time Of Flight) can be used.

MR scans are acquired with the patient positioned as in CT scanning, head first supine on a flat couch overlay (Fig. 1). The 3D MPRAGE sequence covers the entire head and a fragment of the cervical spine with 1 mm slices, with TR = 1390 ms and TE = 3.01 ms. The CISS sequence covers a slab of up to 10 cm of the head with the trigeminal nerve root located in the center. The CISS slice distance is 0.7 mm, with TR = 6.85 ms and TE = 3.43 ms.

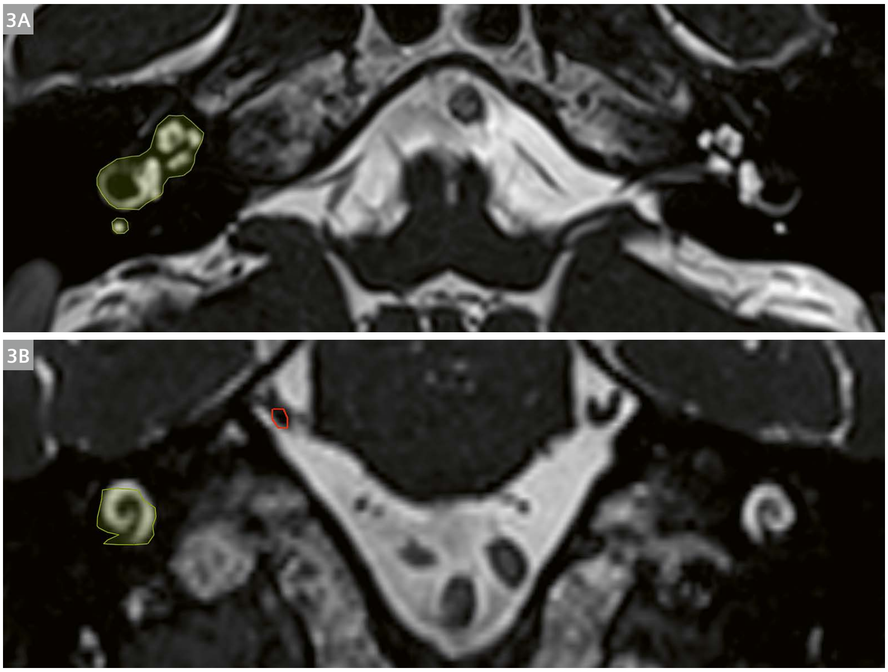
The patient's position during MR scanning should be as close as possible to the position during the CT scan. This approach facilitates image registration and contouring, especially for the brainstem and medulla which can move significantly during flexion and extension of the neck.

Treatment planning aspects

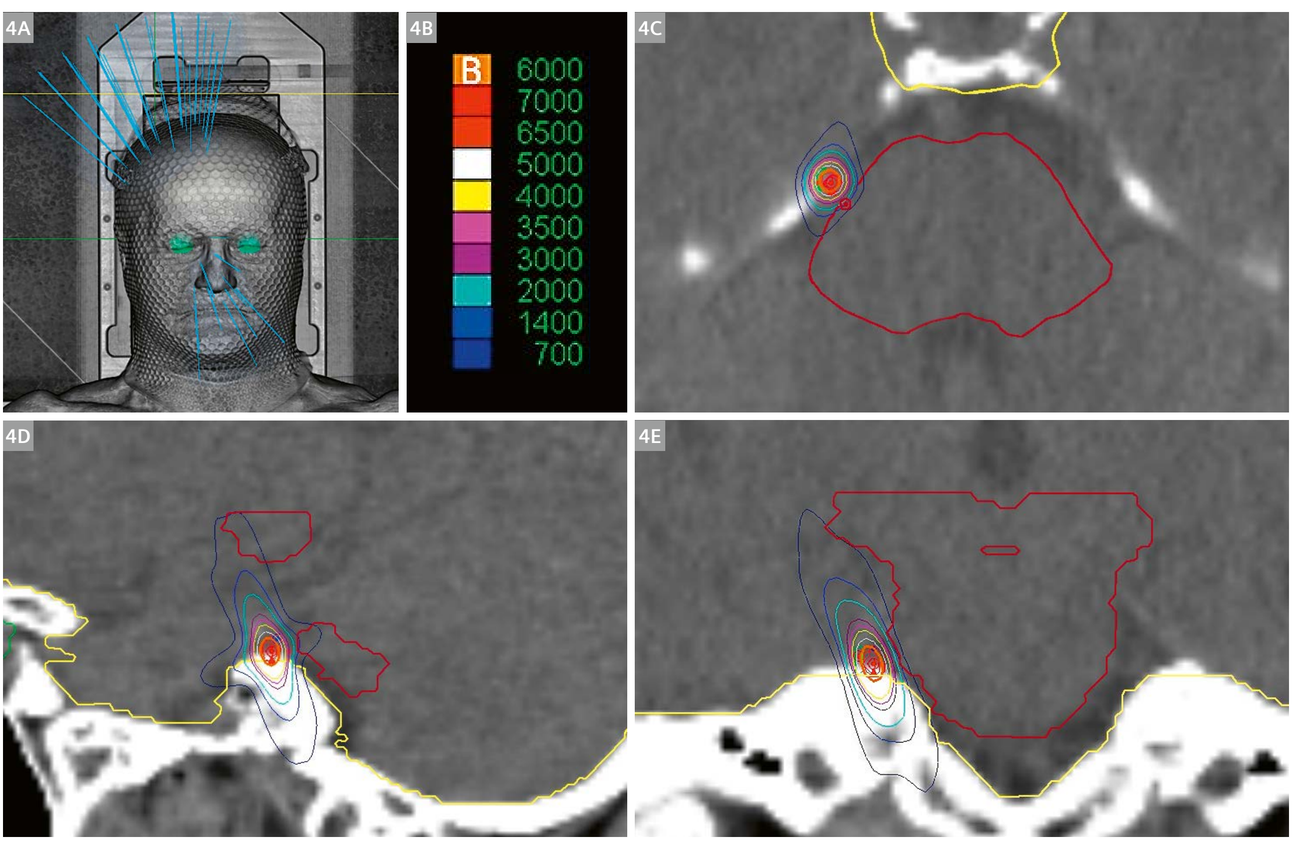
The fusion of CT and MR images, regardless of the contouring and planning system, must be performed with care. Modern systems offer both automatic and manual rigid image registration. The planner must not rely solely on the automatic registration. Taking into account as many factors as possible during the image fusion is crucial in order to obtain the correct results. For CT/3D MPRAGE MR fusion, the anatomy of contrasted vessels, and the shapes of the brainstem and the medulla oblongata are analyzed. CT/CISS MR registration is performed taking into account the shapes of the brainstem, medulla, auditory nerve, and inner ear structures (Fig. 2).



2 Transversal scans at the level of the target volume: **(2A)** CT with barely visible trigeminal nerve and brainstem; **(2B)** T1-weighted MPRAGE with barely visible trigeminal nerve, but well visible brainstem, **(2C)** T2-weighted CISS with clearly visible trigeminal nerve, brainstem and surrounding structures.



3 T2-weighted CISS in treatment planning system **(3A)** transversal image with contour of right inner ear structures (yellow), **(3B)** coronal image with contour of right cochlea (yellow) and trigeminal nerve (red).



4 CyberKnife treatment plan for trigeminal neuralgia. **(4A)** 3D body surface reconstruction and beam arrangement, **(4B)** isocurve scale; structure delineation and dose distribution on the **(4C)** transversal, **(4D)** sagittal and **(4E)** coronal plane.

Delineation of the target and critical organs is done on CT images taking into account two fusions: the 3D MPRAGE and CISS sequences. The CISS sequence is the primary one for target and inner ear contouring (Fig. 3).

The goal of trigeminal neuralgia radiosurgery planning is to obtain a very high point dose in the target and a steep dose gradient outside the target where the nearest critical structures are located.

An acceptable plan must meet certain criteria for these critical structures, especially the brainstem but also the inner ear. In our center, for example, the dose delivered to the brainstem must not exceed 15 Gy and a dose of 10 Gy cannot be delivered in a volume larger than 0.5 cm^3. The doses in other critical structures farther from the target, such as the optic pathway, eyeballs, and lenses, are always monitored. Sparing organs at risk is a higher priority than target dose coverage.

Treatment plan evaluation requires careful reviewing of dose-volume histograms and CT scans one by one. It allows for controlling the dose distribution in the target area and capturing possible hotspots distant from the region of interest (Fig. 4).

Summary

Every year, more than a dozen trigeminal neuralgia treatments are performed at our Institute. CT imaging alone cannot show specific anatomical volumes with sufficient precision, but these small structures are more evident on different MR sequences. Therefore, it is essential to achieve the highest possible accuracy in registering of CT and specific MR sequences. Our institutional protocol for all patients with trigeminal neuralgia includes the registration of CT and 3D MPRAGE without and with contrast enhancement as well as a CISS sequence. Thanks to high resolution imaging, the CISS sequence allows for accurate delineation of the target volume i.e. the fifth cranial nerve, and organs at risk surrounding the target, including cranial nerves and the structures of inner ear. MR imaging is absolutely necessary as the base of exact target and critical structures delineation, allowing a high dose gradient in stereotactic plans to be achieved.

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