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Original article

The EPTN consensus-based atlas for CT- and MR-based contouring in neuro-oncology

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ABSTRACT

Purpose: To create a digital, online atlas for organs at risk (OAR) delineation in neuro-oncology based on high-quality computed tomography (CT) and magnetic resonance (MR) imaging.
Methods: CT and 3 Tesla (3T) MR images (slice thickness 1 mm with intravenous contrast agent) were obtained from the same patient and subsequently fused. In addition, a 7T MR without intravenous contrast agent was obtained from a healthy volunteer. Based on discussion between experienced radiation oncologists, the clinically relevant organs at risk (OARs) to be included in the atlas for neuro-oncology were determined, excluding typical head and neck OARs previously published. The draft atlas was delineated by a senior radiation oncologist, 2 residents in radiation oncology, and a senior neuro-radiologist incorporating relevant available literature. The proposed atlas was then critically reviewed and discussed by European radiation oncologists until consensus was reached.
Results: The online atlas includes one CT-scan at two different window settings and one MR scan (3T) showing the OARs in axial, coronal and sagittal view. This manuscript presents the three-dimensional descriptions of the fifteen consensus OARs for neuro-oncology. Among these is a new OAR relevant for neuro-cognition, the posterior cerebellum (illustrated on 7T MR images).
Conclusion: In order to decrease inter- and intra-observer variability in delineating OARs relevant for neuro-oncology and thus derive consistent dosimetric data, we propose this atlas to be used in photon and particle therapy. The atlas is available online at www.cancerdata.org and will be updated whenever required.

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In order to evaluate the added value of new radiotherapy (RT) modalities and techniques, such as particle therapy and adaptive highly conformal photon RT, it is essential to be able to accurately predict the individual patient's benefit in term of radiation-induced side effects [1–3]. The maturation and validation of normal tissue complication probability (NTCP) models are strongly dependent on uniform delineation of the relevant organs at risk (OARs), and reducing the inter- and intra-observer and trial protocol variability between clinicians and radiotherapy departments is an important objective. In this context, Brouwer et al. [4] and Kong et al. [5] published atlases for OARs relevant for head and neck and lung tumors, respectively.

During the last decade, several papers have been published on the delineation of OARs relevant to neuro-oncology both for adults and children [4,6,7]. These atlases may differ in minor details, but also some major discrepancies might occur, for instance, variations in the upper limit of the brainstem. Discrepancies in a critical OAR may influence the dose distribution and thus compromise the coverage of the target volume [4,6].

Within the Dutch Platform for Neuro-Oncology and the ESTRO taskforce "European Particle Therapy Network (EPTN)" there was a need to generate an atlas, which identifies the relevant OARs for neuro-oncology and can be used both for daily practice as well as research purposes [8]. With the ever-growing insight into the influence of radiotherapy on neurological functions, it is essential that this atlas can be easily updated when indicated.

Selection of OARs

In order to avoid overlap with existing head and neck atlases, typical head and neck OARs, which were previously published, were excluded from this consensus atlas [4]. All OARs at present known to be relevant for radiation-induced toxicity in neuro-oncology were included, namely: brain, brainstem, cochlea, vestibulum & semicircular canals, cornea, lens, retina, lacrimal gland, optic nerve, chiasm, pituitary, hippocampus and skin. In case of paired organs, each organ separately (left and right), and the unity of the two were contoured.

For future development of NTCP models, three distinct parts for the brainstem were defined, and regarding cognition, the posterior cerebellum, a new OAR possibly involved was included, as was the separation of the hippocampus into anterior and posterior parts. For research purposes also the hypothalamus was included. Of note, no validated dose–response curve relationships have thus far been published for these separate parts of the brainstem, hippocampus and cerebellum.

Uniform nomenclature

To facilitate future comparison of the structures, the proposed nomenclature is in accordance with work by Santanam et al. [9] on standardizing naming convention in radiation oncology, illustrated with quotes between brackets behind every structure name, for example: retina *("Retina_R", "Retina_L" and "Retinas").*

Delineation

The fifteen OARs introduced in several previous publications were delineated by the first author (DE) [4,6,7]. The anterior and posterior cerebellums were delineated by three authors (DE, LV, IC) using the high-resolution segment of the radiation treatment planning software (Eclipse™ v11.0 software, Varian, Palo Alto, CA). During a multi-disciplinary session, the senior radiation oncologist (DE), neuro-radiologist (AP), and two residents in radiation oncology (LV, IC) discussed the delineation of the OARs and came to consensus on a first draft atlas. This draft was then critically reviewed by Dutch and international experts in neuro-oncology and consensus on the final version of this atlas was reached.

Acquisition of CT and MR

CT images were acquired with intravenous contrast (Ultravist®, 150 ml of 300 mg Iodine per mL, 2 mL per sec, 5 min delay, slice thickness 1 mm, 50 cm field of view, 120 kV, 685 mAs) using window-width/window-level settings (WW/WL) of 120/40 and 120/1500 (SOMATOM Sensation 10, Siemens Healthcare, Erlangen, Germany) of the head of an adult male low grade glioma patient after first resection. Moreover, a three-dimensional spoiled gradient (3D-SPGR) axial 3T MR scan (1 mm slice thickness) of the same patient in standard axial, sagittal and coronal reconstruction, and an axial T2- and a gadolinium (Gadovist® 1.0 mmol/ml 0.1 mL/kg bodyweight) contrast-enhanced axial T1-weighted sequence were acquired, with sagittal and coronal reconstruction. Both CT and MR were obtained in the supine position with the head in a neutral position; immobilization devices routinely used in radiation therapy were used for CT acquisition. Rigid MR-CT co-registration and delineation were performed using the Eclipse™ treatment planning system with the high-resolution segment.

For illustration purposes, 7T MR images of a healthy volunteer were acquired (Siemens Magnetom 7T) with a slice thickness of 0.7 mm using a 32-channel head coil (Nova Medical Inc., Wilmington, CA; Fig. 1). The magnetization-prepared rapid gradient-echo (MP2RAGE) was selected for OAR delineation due to its superior soft tissue contrast (Fig. 2). Scan parameters have previously been published by Compter et al. [10]. Vendor-based 3D distortion correction methods were applied.

Three-dimensional description of the OARs

Cornea ("Cornea_R", "Cornea_L" and "Corneas")

The cornea is located at the anterior segment of the eyeball consisting of the structures ventral to the vitreous humor, the iris, ciliary body, and lens [6]. Using a brush of 2–3 mm the cornea can easily be delineated on MR as well as CT.

Retina ("Retina_R", "Retina_L" and "Retinas")

The retina is a neurosensorial membrane of 2–3 mm thickness, located at the posterior part of the eyeball, posterior to the cornea and lens, and is the innermost of the three layers that form the wall of the eyeball (sclera, uvea/choroid and retina). Using a 3 mm brush, it can be delineated on MR as well as CT as a membrane covering the posterior 5/6 of the globe, extending nearly as far as the ciliary body. The anterior border of the retina is between the insertion of the medial rectus muscle and the lateral rectus muscle, posterior to the ciliary body. The optic nerve is excluded from this contour [4,6].

Lacrimal gland ("LacrimalGland L", "LacrimalGland_R" and "LacrimalGlands")

The lacrimal gland is an almond shaped gland (18 mm craniocaudally, 15 mm axial length and 5 mm axial width) located in the orbit superior-lateral to the eye, superior to the lateral rectus muscle and lateral to the superior rectus muscle. It can be delineated on CT using soft brain 120/40 or soft tissue 350/50 WW/WL settings [4,6,11].

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