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HaN-Seg: The head and neck organ-at-risk CT and MR segmentation dataset

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Abstract

**Purpose:** For the cancer in the head and neck (HaN), radiotherapy (RT) represents an important treatment modality. Segmentation of organs-at-risk (OARs) is the starting point of RT planning, however, existing approaches are focused on either computed tomography (CT) or magnetic resonance (MR) images, while multimodal segmentation has not been thoroughly explored yet. We present a dataset of CT and MR images of the same patients with curated reference HaN OAR segmentations for an objective evaluation of segmentation methods.

**Acquisition and validation methods:** The cohort consists of HaN images of 56 patients that underwent both CT and T1-weighted MR imaging for image-guided RT. For each patient, reference segmentations of up to 30 OARs were obtained by experts performing manual pixel-wise image annotation. By maintaining the distribution of patient age and gender, and annotation type, the patients were randomly split into training Set 1 (42 cases or 75%) and test Set 2 (14 cases or 25%). Baseline auto-segmentation results are also provided by training the publicly available deep nnU-Net architecture on Set 1, and evaluating its performance on Set 2.

**Data format and usage notes:** The data are publicly available through an open-access repository under the name HaN-Seg: The Head and Neck Organ-at-Risk CT & MR Segmentation Dataset. Images and reference segmentations are stored in the NRRD file format, where the OAR filenames correspond to the nomenclature recommended by the American Association of Physicists in Medicine, and OAR and demographics information is stored in separate comma-separated value files.

**Potential applications:** The HaN-Seg: The Head and Neck Organ-at-Risk CT & MR Segmentation Challenge is launched in parallel with the dataset release to promote the development of automated techniques for OAR segmentation in the HaN. Other potential applications include out-of-challenge algorithm development and benchmarking, as well as external validation of the developed algorithms.

**KEYWORDS**
auto-segmentation, computed tomography, head and neck cancer, image dataset, magnetic resonance, radiation therapy
1 INTRODUCTION

Cancer and its management are among the key challenges of modern society in the contexts of health and quality of life. Cancer of the head and neck (HaN) region, comprising malignancies of the lips, oral cavity, pharynx, larynx, nasal cavity, paranasal sinuses, salivary glands, thyroid, and skin of this region, is potentially associated with swallowing dysfunction, speech and breathing problems, disfigurement, psychosocial distress, and death.1 With a yearly incidence of above one million cases and prevalence of above four million cases worldwide, it is one of the most frequent cancers, accounting for around 5% of all cancer sites.2,3

Radiotherapy (RT) is one of the key treatment modalities for the HaN cancer that aims to deliver a high radiation dose to the targeted cancerous cells while sparing the nearby healthy tissues and organs, that is, organs-at-risk (OARs). In the past years, advances in RT have, in parallel with improvements in less-invasive organ-sparing surgery as well as more intensive multimodal treatments, contributed to the preservation of function and reduced mortality of the HaN cancer.1 Among these advances, a considerable progress has been made in artificial intelligence (AI) and especially deep learning (DL) as one of its subdomains,4,5 which has a large spectrum of applications also in radiation oncology. For example, segmentation as the process of partitioning a medical image into multiple anatomical structures is one of the key steps in RT planning,6 because it provides precise three-dimensional (3D) spatial descriptions of the target volumes as well as OARs that are required for an optimal radiation dose distribution calculation. While manual image segmentation has been recognized as a labor-intensive and time-consuming task that is subjected to intra/interobserver variability,7 several computerized medical image analysis techniques have been developed for automated segmentation, often referred to as auto-segmentation.8 In comparison to traditional approaches based on conventional atlases, shape models, and feature classification, the advent of DL has caused a shift towards a superior segmentation performance.5,9 Although segmentation is primarily performed on computed tomography (CT) images because they contain electron density information used for the calculation of the radiation beam energy absorption, one of the main limitations of CT images is the insufficient image contrast for soft tissues. As a result, the integration of complementary imaging modalities, such as magnetic resonance (MR), is strongly recommended for the HaN region to improve the segmentation of several soft tissue OARs.10

Although attempts have been made towards the segmentation of OARs from MR images,11–15 so far there has been no objective evaluation about the impact the combined analysis of CT and MR images has on the segmentation of OARs in the HaN region. Most of the existing approaches are focused on segmentation from either CT or MR image modality, while multimodal segmentation has not been thoroughly explored yet,9 probably because CT and MR data of the same patients are not always available or, when they are available, they are not systematically included into the RT planning pipeline. In this paper, we describe a collection of CT and MR images of the same patients with the corresponding curated expert manual segmentations of the complete set of OARs in the HaN region, which aims to promote research in the fields of multimodal and multi-organ auto-segmentation,16 and MR-guided RT planning.17,18

2 ACQUISITION AND VALIDATION METHODS

2.1 Images

Images of 60 patients aged 34–79 years that were appointed for image-guided RT in the HaN region at the Institute of Oncology Ljubljana, Slovenia (Ethics Committee approval no. ERID-EK/139), and underwent both CT and MR image acquisition were retrospectively retrieved from the picture archiving and communication system (PACS). CT images were acquired with either the Philips Brilliance Big Bore (Philips Healthcare, Best, the Netherlands) or Siemens Somatom Definition AS scanner (Siemens Healthineers, Erlangen, Germany) by using standard clinical protocols (x-ray tube voltage: 100–140 kV; field of view [FoV]: (500 × 500)−(800 × 800) mm²). All MR images were acquired with the GE Medical Systems Optima MR450w scanner (GE Healthcare, Chicago, IL, USA) by using either the spin echo (SE; flip angle: 160°, echo time: 8.7 ms, repetition time: 472–743 ms; axial T1-weighted fast SE cross-sections with fat saturation—Ax T1 FSE FS) or gradient echo (GR; flip angle: 12°, echo time: 3.1 ms, repetition time: 6.1–8.3 ms; axial T1-weighted ultra fast spoiled GR cross-sections with water only, fat only, in phase and out of phase echoes and homogeneous fat suppression—Ax T1 WATER LAVA FS) sequence (FoV: (240 × 240)−(420 × 420) mm²). The time intervals between CT and MR image acquisition were relatively short, and amounted on average to 1.8 ± 1.7 days (median: 1 day, range: 0–11 days), with MR images always being acquired after CT images. Both images were acquired in patient standard head-first supine (HFS) position, and by using Posticast® 5-point thermoplastic immobilization masks (CIVCO Radiotherapy, Orange City, IA, USA) that were also used for patient irradiation.

Due to the presence of metal artifacts, several CT images contained regions with Hounsfield units (HU)
above 3000, which were consequently set to 3000 to ensure a range of HU that allows easier image visualization. From the initial cohort, one patient was excluded because of poor MR image quality, and three because of the insufficient MR image FoV. The resulting cohort, therefore, consists of 56 cases, where each case is represented by one CT and one T1-weighted MR image of the HaN region of the same patient (Figure 1). Furthermore, the standard arrangement in public competitions of medical image analysis algorithms is to disclose
only part of the data indented for algorithm training, while the nondisclosed data are then used for objective algorithm comparison. By following such an arrangement, the cases were randomly split into two sets by maintaining the distribution of patient age and gender (Figure 2), where 42 cases (75%) from Set 1 are publicly available and 14 cases (25%) from Set 2 are held private. The basic properties of the whole cohort are listed in Table 1.

### 2.2 Reference manual segmentation

To enable the development of auto-segmentation methods and evaluation of the obtained segmentation results, we provide reference OAR segmentation masks for CT images in the devised dataset. Initial segmentations were obtained by experts from the Institute of Oncology Ljubljana, Slovenia, who performed manual pixel-wise image annotation of up to 31 OARs (or 23, considering the left and right instances of paired OARs as one instance) in CT images (MR images were used as a support for soft tissues) according to the standard RT planning practice and by following the established guidelines for the delineation of OARs in the HaN region. Approximately half of the cohort (i.e., 29 cases) was annotated by an experienced RT technologist, trained specifically for the delineation of OARs. In this case, each MR image was first registered to the CT image of the same patient, and then OARs were annotated in the reference coordinate system of the CT image. The rest of the cohort (i.e., 27 cases) was annotated by a group of radiation oncologists, experienced in the delineation of OARs. In this case, each MR image was first registered to the CT image of the same patient, and then OARs were annotated in the reference coordinate system of the CT image. The obtained annotations were then curated by a medical imaging researcher, experienced in annotation of anatomical structures, who manually corrected the

<table>
<thead>
<tr>
<th>TABLE 1 Properties of patients, and computed tomography (CT), and magnetic resonance (MR) images in the devised HaN-Seg dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sets</strong></td>
</tr>
<tr>
<td><strong>No. of cases</strong></td>
</tr>
<tr>
<td>1 and 2</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

The obtained annotations were then curated by a medical imaging researcher, experienced in annotation of anatomical structures, who manually corrected the
OAR segmentation masks (i.e., jagged boundaries, isolated pixels, mis-annotations, mis-labeling, connected components, etc.). In this process, the following two major inconsistencies were in addition identified. First, the experts often decided not to extend the segmentation masks of the carotid arteries to the optic chiasm, as recommended by the delineation guidelines, but only to the pituitary gland (i.e., approximately 10 mm caudally from the optic chiasm). In order to make the segmentation masks of the carotid arteries consistent among all cases, which is an important aspect when training and evaluating the performance of auto-segmentation methods, they were cut off below the pituitary gland. Second, the segmentation masks of pharyngeal constrictor muscles were often overlapping by a large extent with other OARs (e.g., oral cavity, larynx), moreover, their shape often alternated considerably between adjacent axial slices, therefore not resembling a connected and unified anatomical structure. As a result, the annotations of pharyngeal constrictor muscles were found to be not reliable enough, and were, therefore, not included in the final dataset.

All corrections were performed with the publicly available Seg3D software (version 2.5.0, NIH Center for Integrative Biomedical Computing, Scientific Computing and Imaging Institute, University of Utah, Salt Lake City, UT, USA; https://www.sci.utah.edu/cibc-software/seg3d.html). By not including the annotations of pharyngeal constrictor muscles in the final dataset, reference annotations of up to 30 OARs (or 22, considering the left and right instances of paired OARs as one instance) were obtained for each case in the form of 3D binary segmentation masks (Figure 3) and named according to the nomenclature proposed by the Task Group 263 (TG-263) of the American Association of Physicists in Medicine (AAPM), that is, arytenoids (Arytenoid), brainstem (Brainstem), carotid artery (A_Carotid; left/right: A_Carotid_L/A_Carotid_R), cervical esophagus (Esophagus_S), cochlea (Cochlea; left/right: Cochlea_L/Cochlea_R), cricopharyngeal inlet (Cricopharyngeus), lacrimal gland (Glnd_Lacrimal; left/right: Glnd_Lacrimal_L/Glnd_Lacrimal_R), larynx—glottis (Glottis), larynx—supraglottic (Larynx_SG), lips (Lips), mandible (Bone_Mandible), optic chiasm (OpticChiasm), optic nerve (OpticNrv; left/right: OpticNrv_L/OpticNrv_R), oral cavity (Cavity_Oral), parotid gland (Parotids; left/right: Parotid_L/Parotid_R), pituitary gland (Pituitary), spinal cord (SpinalCord), submandibular gland (Glnd_Submand; left/right: Glnd_Submand_L/Glnd_Submand_R), and thyroid (Glnd_Thyroid). For OARs that were not found in the AAPM TG-263 nomenclature, that is, buccal mucosa (BuccalMucosa), anterior segment of the eyeball (Eye_A; left/right: Eye_AL/Eye_AR), and posterior segment of the eyeball (Eye_P; left/right: Eye_PL/Eye_PR), we followed a similar naming convention that was combined with the nomenclature in the delineation guidelines. An example of the obtained reference segmentations is shown in Figure 4.

2.3 Baseline auto-segmentation

To provide baseline auto-segmentation results, we applied a publicly available framework for DL-based
segmentation named nnU-Net\textsuperscript{21} (https://github.com/MIC-DKFZ/nnUNet). By building on the U-Net architecture,\textsuperscript{22} nnU-Net adds self-configurable preprocessing, augmentation, and post-processing techniques, and employs modern strategies for an efficient training, which proved to generate state-of-the-art results on several publicly available datasets used in different biomedical image segmentation challenges. We trained the nnU-Net framework on images and corresponding reference segmentations from Set 1, for which each pair of CT and MR images was first registered by finding the optimal rigid (i.e., translation and rotation) and nonrigid (i.e., B-splines) geometrical alignment with SimpleElastix (version 0.10.0; https://simpleelastix.github.io), an extension of the open-source image registration toolbox elastix.\textsuperscript{23} The registration quality was evaluated by first placing corresponding landmarks at six anatomical locations that could be reliably identified in both CT and MR images (i.e., at the nasal tip, the posterior edge of the skull at the height of the nasal tip, the posterior edge of the left/right angle of the mandible, and at the approximate junction between the vertebral lamina and left/right transverse process of a C3–C6 vertebral level), and then computing the distance between each pair of corresponding landmarks after registration, that is, the target registration error (TRE). The resulting mean TRE of 1.5 mm (standard deviation: 0.5 mm; maximum: 3.5 mm) is consistent with the AAPM Task Group 132 recommendations,\textsuperscript{24} which state that the mean TRE below 2 mm (maximum below 5 mm) is typically desired for the majority of clinical applications, that is, below the tolerance equal to the maximum voxel dimension, which is in our case 2–5 mm.

Before training, all images were also spatially resampled to the same pixel size of 0.5 mm × 0.5 mm and spacing of 2 mm (Table 1), and HUs were set to the interval between −1000 and 3000 to correct for eventual interpolation errors. A single nnU-Net model was then trained for 1000 epochs on all 42 pairs of CT and MR images (no external images were used), and for all OARs using the 3d\_fullres configuration (the only modification was that the data augmentation for image flipping across the sagittal axis was disabled). The obtained nnU-Net model was then evaluated on images and corresponding reference segmentations from Set 2, and the results are reported in Table 2 in terms of the Dice coefficient (DC), a standard metrics for volumetric mask overlap that measures the harmonic average of the classification precision and recall (i.e., the F\textsubscript{1} score), and Hausdorff distance (HD), a standard metrics for distance measurement that evaluates the mutual proximity of the segmentation mask surfaces, where its 95-percentile version (HD\textsubscript{95}) is often used to robustly suppress the influence of the outliers.\textsuperscript{9} As MR images commonly have, in comparison to CT images, a smaller FoV, CT images were cropped to the FoV of MR images. Consequently, the metrics were computed only for those OARs that retained more than 20% of their original volume after cropping. The whole framework was implemented in the Python programming language (version 3.7.10; https://www.python.org).

3 | DATA FORMAT AND USAGE NOTES

The devised Set 1 can be publicly accessed and downloaded through the open-access repository Zenodo (https://zenodo.org) under the collection HaN-Seg: The Head and Neck Organ-at-Risk CT & MR Segmentation Dataset (https://doi.org/10.5281/zenodo.7442914), with the condition that any research originating from the
TABLE 2 The baseline auto-segmentation results for the devised dataset, obtained by training nnUNet++ on Set 1 and evaluating its performance on organs-at-risk (OARs) in Set 2 (i.e., N = 28 for both and 14 for individual instances of left/right OARs, or less when an OAR was not in the field of view). The reported values are mean ± standard deviation of the Dice coefficient (DC) and 95-percentile Hausdorff distance (HD₉₅).

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>OAR name</th>
<th>N</th>
<th>DC (%)</th>
<th>HD₉₅ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_Carotid</td>
<td>Carotid arteries (both)</td>
<td>28</td>
<td>84.7 ± 3.4</td>
<td>1.6 ± 1.2</td>
</tr>
<tr>
<td>A_Carotid_L</td>
<td>Carotid artery (left)</td>
<td>14</td>
<td>84.4 ± 4.0</td>
<td>1.7 ± 1.2</td>
</tr>
<tr>
<td>A_Carotid_R</td>
<td>Carotid artery (right)</td>
<td>14</td>
<td>85.0 ± 2.6</td>
<td>1.5 ± 1.1</td>
</tr>
<tr>
<td>Arytenoid</td>
<td>Arytenoids</td>
<td>13</td>
<td>56.3 ± 17.9</td>
<td>3.1 ± 1.5</td>
</tr>
<tr>
<td>Bone_Mandible</td>
<td>Mandible</td>
<td>14</td>
<td>94.4 ± 1.6</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>Brainstem</td>
<td>Brainstem</td>
<td>13</td>
<td>86.0 ± 4.2</td>
<td>4.5 ± 1.9</td>
</tr>
<tr>
<td>BuccalMucosa</td>
<td>Buccal mucosa</td>
<td>13</td>
<td>69.4 ± 9.7</td>
<td>6.0 ± 2.7</td>
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<tr>
<td>Cavity_Oral</td>
<td>Oral cavity</td>
<td>14</td>
<td>90.2 ± 3.6</td>
<td>4.7 ± 2.1</td>
</tr>
<tr>
<td>Cochlea</td>
<td>Cochlea (both)</td>
<td>26</td>
<td>72.8 ± 11.4</td>
<td>1.7 ± 1.0</td>
</tr>
<tr>
<td>Cochlea_L</td>
<td>Cochlea (left)</td>
<td>13</td>
<td>74.6 ± 11.1</td>
<td>1.5 ± 0.9</td>
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<tr>
<td>Cochlea_R</td>
<td>Cochlea (right)</td>
<td>13</td>
<td>71.1 ± 11.4</td>
<td>1.8 ± 1.0</td>
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<tr>
<td>Cricopharyngeus</td>
<td>Cricopharyngeal inlet</td>
<td>9</td>
<td>63.2 ± 13.1</td>
<td>5.5 ± 3.0</td>
</tr>
<tr>
<td>Esophagus_S</td>
<td>Cervical esophagus</td>
<td>5</td>
<td>64.2 ± 13.0</td>
<td>6.8 ± 2.3</td>
</tr>
<tr>
<td>Eye_A</td>
<td>Anterior eyeball segment (both)</td>
<td>15</td>
<td>82.2 ± 4.5</td>
<td>1.8 ± 0.3</td>
</tr>
<tr>
<td>Eye_AL</td>
<td>Anterior eyeball segment (left)</td>
<td>7</td>
<td>82.2 ± 3.7</td>
<td>1.7 ± 0.3</td>
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<tr>
<td>Eye_AR</td>
<td>Anterior eyeball segment (right)</td>
<td>8</td>
<td>82.2 ± 5.1</td>
<td>1.9 ± 0.4</td>
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<tr>
<td>Eye_P</td>
<td>Posterior eyeball segment (both)</td>
<td>17</td>
<td>92.6 ± 1.6</td>
<td>1.6 ± 0.5</td>
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<tr>
<td>Eye_PL</td>
<td>Posterior eyeball segment (left)</td>
<td>8</td>
<td>93.0 ± 1.8</td>
<td>1.6 ± 0.5</td>
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<tr>
<td>Eye.PR</td>
<td>Posterior eyeball segment (right)</td>
<td>9</td>
<td>92.3 ± 1.4</td>
<td>1.5 ± 0.4</td>
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<tr>
<td>Gldn_Lacrimal</td>
<td>Lacrimal glands (both)</td>
<td>15</td>
<td>62.6 ± 13.1</td>
<td>3.2 ± 1.3</td>
</tr>
<tr>
<td>Gldn_Lacrimal_L</td>
<td>Lacrimal gland (left)</td>
<td>7</td>
<td>63.1 ± 13.0</td>
<td>3.1 ± 1.5</td>
</tr>
<tr>
<td>Gldn_Lacrimal_R</td>
<td>Lacrimal gland (right)</td>
<td>8</td>
<td>62.1 ± 13.1</td>
<td>3.3 ± 1.2</td>
</tr>
<tr>
<td>Gldn_Submands</td>
<td>Submandibular glands (both)</td>
<td>26</td>
<td>84.4 ± 8.1</td>
<td>3.7 ± 2.6</td>
</tr>
<tr>
<td>Gldn_Submand_L</td>
<td>Submandibular gland (left)</td>
<td>13</td>
<td>84.8 ± 9.1</td>
<td>3.2 ± 2.2</td>
</tr>
<tr>
<td>Gldn_Submand_R</td>
<td>Submandibular gland (right)</td>
<td>13</td>
<td>84.0 ± 6.9</td>
<td>4.2 ± 2.9</td>
</tr>
<tr>
<td>Gldn_Thyroid</td>
<td>Thyroid</td>
<td>6</td>
<td>90.3 ± 2.3</td>
<td>1.5 ± 0.6</td>
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<tr>
<td>Glottis</td>
<td>Larynx—glottis</td>
<td>12</td>
<td>75.2 ± 7.8</td>
<td>2.7 ± 1.3</td>
</tr>
<tr>
<td>Larynx_SB</td>
<td>Larynx—supraglottic</td>
<td>13</td>
<td>81.4 ± 4.3</td>
<td>3.5 ± 1.2</td>
</tr>
<tr>
<td>Lips</td>
<td>Lips</td>
<td>14</td>
<td>72.2 ± 10.8</td>
<td>6.5 ± 2.8</td>
</tr>
<tr>
<td>OpticChiasm</td>
<td>Optic chiasm</td>
<td>9</td>
<td>44.3 ± 8.7</td>
<td>4.0 ± 1.5</td>
</tr>
<tr>
<td>OpticNrv</td>
<td>Optic nerves (both)</td>
<td>18</td>
<td>72.2 ± 8.1</td>
<td>2.3 ± 0.7</td>
</tr>
<tr>
<td>OpticNrv_L</td>
<td>Optic nerve (left)</td>
<td>9</td>
<td>69.9 ± 8.5</td>
<td>2.6 ± 0.8</td>
</tr>
<tr>
<td>OpticNrv_R</td>
<td>Optic nerve (right)</td>
<td>9</td>
<td>74.6 ± 7.0</td>
<td>2.1 ± 0.5</td>
</tr>
<tr>
<td>Parotids</td>
<td>Parotid glands (both)</td>
<td>28</td>
<td>86.3 ± 3.6</td>
<td>5.3 ± 3.6</td>
</tr>
<tr>
<td>Parotid_L</td>
<td>Parotid gland (left)</td>
<td>14</td>
<td>87.1 ± 2.8</td>
<td>5.9 ± 4.4</td>
</tr>
<tr>
<td>Parotid_R</td>
<td>Parotid gland (right)</td>
<td>14</td>
<td>85.6 ± 4.1</td>
<td>4.7 ± 2.1</td>
</tr>
<tr>
<td>Pituitary</td>
<td>Pituitary gland</td>
<td>13</td>
<td>70.3 ± 1.9</td>
<td>2.5 ± 1.4</td>
</tr>
<tr>
<td>SpinalCord</td>
<td>Spinal cord</td>
<td>13</td>
<td>82.1 ± 4.7</td>
<td>1.7 ± 0.4</td>
</tr>
</tbody>
</table>

The usage of the HaN-Seg dataset needs to cite this paper. Images and reference segmentation masks are provided in the compressed nearly raw raster data (NRRD) file format (.nrrd extension), a common format for the representation and processing of multidimensional raster data that can be loaded and processed by most medical image analysis software (e.g., ImageJ, Seg3D, ITK, 3D Slicer, etc.) as well as programming languages via dedicated libraries (e.g., Matlab—Image Processing Toolbox, Python—SimpleITK package, etc.). Specifically, for each case (case<n>_IMG_CT.nrrd)
4 | POTENTIAL APPLICATIONS

For the devised HaN-Seg dataset, we have identified the following three main potential applications, that is, A. Computational challenge, B. Algorithm development and benchmarking, and C. External validation, although other applications may arise.

4.1 | Computational challenge

In parallel with the release of this dataset, we are also launching the HaN-Seg: The Head and Neck Organ-at-Risk CT & MR Segmentation Challenge (https://han-seg2023.grand-challenge.org) to promote the development of new and application of existing state-of-the-art fully automated techniques for OAR segmentation in the HaN region from CT images that exploit the information of multiple imaging modalities, in this case from CT and MR images. The task of the HaN-Seg challenge is to automatically segment up to 30 OARs in the HaN region from CT images in the devised Set 2, consisting of 14 CT and MR images of the same patients, given the availability of Set 1, consisting of 42 CT and MR images of the same patients with reference 3D OAR binary segmentation masks for CT images, that is, the herein described HaN-Seg dataset. From this perspective, Set 2 is held private and therefore not released to the potential participants to prevent algorithm tuning, but instead the algorithms have to be submitted in the form of virtual containers that will be run by organizers on Set 2. The challenge is organized by taking into account the current guidelines for biomedical image analysis competitions, in particular, the recommendations of the Biomedical Image Analysis Challenges (BIAS) initiative for transparent challenge reporting.

4.2 | Algorithm development and benchmarking

Apart from participating in the HaN-Seg challenge described above, researchers can also use the HaN-Seg dataset for algorithm development, and, most importantly, for benchmarking the obtained segmentation results. Specific fields within medical image analysis and RT where CT and MR images of the same patients may be beneficial, are, for example, OAR segmentation in the HaN region, multi-organ segmentation, synthetic MR image generation for segmentation support, MR-guided RT planning, or synthetic CT image generation for MR-only RT.

4.3 | External validation

External validation is the process of using independently derived datasets to validate the performance of an AI method, commonly also known as real-world validation. Researchers may use the devised HaN-Seg dataset for external validation as well as for other...
5 | DISCUSSION

In radiation oncology, AI models allow automation and optimization of the workflow,\(^4\) and DL as a subset of AI has become the dominant methodology for auto-segmentation of medical images.\(^5\) Because it has been recognized as extremely useful for RT planning, OAR auto-segmentation is a very widespread research topic, including approaches focused on the HaN region.\(^9\)

Considering the general incidence and prevalence of the HaN cancer,\(^2\) several datasets of HaN images that are used for its diagnosis and treatment have been devised in the past. Some of these datasets are publicly available, for example, via The Cancer Imaging Archive (TCIA) that currently hosts 11 collections related to the HaN cancer. However, not all of them are associated with reference OAR segmentations, but were augmented and combined into new publicly available datasets. For example, 48 CT images from one TCIA dataset (Head-Neck Cetuximab) were annotated with annotations of nine OARs into the Public Domain Database for Computational Anatomy (PDDCA)\(^10\) (http://www.imagenglab.com/newsite/pddca/), 31 CT images from two TCIA datasets (Head-Neck Cetuximab and TCGA-HNSC) were augmented with annotations of 21 OARs into the TCIA Test & Validation Radiotherapy CT Planning Scan Dataset\(^41\) (https://github.com/deepmind/tcia-ct-scan-dataset/), while 140 CT images from two TCIA datasets (Head-Neck Cetuximab and Head-Neck-PET-CT) and 175 in-house CT images were augmented with annotations of 28 OARs into the UaNet Dataset\(^42\) (https://github.com/uci-cbcl/UaNet/). Other HaN datasets that are publicly available but do not originate from TCIA are the StructSeg Dataset of 50 CT images with annotations of 22 OARs (https://structseg2019.grand-challenge.org/Dataset/), and the MRI-RT Dataset\(^43\) of 15 CT and 15 MR images of the same patients. Considering the general prevalence and incidence of the HaN cancer, we can observe that most of them are focused on either CT or MR images, with the exception of the MRI-RT Dataset\(^43\) that contains both CT and MR image pairs of the same patients. However, this dataset is more oriented towards MR-to-CT registration than segmentation, moreover, it is not associated with any challenge that would probably increase its visibility. We can, therefore, conclude that, to the best of our knowledge, to this date no other publicly available dataset exists for the evaluation of auto-segmentation methods given both CT and MR images of the same patients. From the perspective of dataset size, the HaN-Seg dataset consists of 56 CT/MR image pairs, and is, therefore, comparable to other publicly available datasets. On the other hand, from the perspective of OAR annotation, it contains reference segmentations of the most complete set of 30 OARs in the HaN region. Finally, from the perspective of auto-segmentation performance, the baseline results obtained by an off-the-shelf DL solution (i.e., nnU-Net) are inferior to the results reported by existing CT-only DL methods\(^9\) but still comparable to some recent state-of-the-art DL methods.\(^44\) With the release of the HaN-Seg dataset and deployment of the accompanying HaN-Seg challenge, our aim is, therefore, to test the hypothesis that the accuracy and reliability of OAR segmentation can be improved by exploiting the fused information from both CT and MR images, with the objective to design, develop, and evaluate novel auto-segmentation algorithms that rely on robust and accurate registration algorithms and can be benchmarked on a common dataset. Considering the recent growth in the application of AI, especially DL,\(^45\) the devised HaN-Seg dataset has also the potential to contribute to a more objective and trustful reporting of research outcomes. Nevertheless, future versions of the HaN-Seg dataset may be enriched with additional CT/MR image pairs to capture a wider distribution of the anatomical variability among patients\(^10\) or additional reference segmentations to evaluate the interobserver variability of manual annotation,\(^7\) as well as with radiation dose distribution maps as defined by RT planning to evaluate the dosimetric impact of auto-segmentation results.\(^46\)

6 | CONCLUSION

In this paper, we have described the publicly available HaN-Seg dataset consisting of 56 CT and MR images of the same patients with corresponding topics related to the dataset, such as for evaluating different learning strategies\(^38\) or the impact of the training set size on the performance of an AI method.\(^39\)
reference segmentations of 30 OARs in the HaN region, and the accompanying HaN-Seg challenge, which aim to investigate the potential of multimodal imaging for the development of new and application of existing state-of-the-art OAR auto-segmentation algorithms. The outcomes will indicate whether the utilization of multimodal CT/MR image information is beneficial for obtaining more accurate and reliable OAR segmentation results, and therefore potentially aid clinical practice.

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CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT
The devised Set 1 can be publicly accessed and downloaded through the open-access repository Zenodo (https://zenodo.org) under the collection HaN-Seg: The Head and Neck Organ-at-Risk CT & MR Segmentation Dataset (https://doi.org/10.5281/zenodo.7442914).

REFERENCES


