Diffusion-weighted MRI in head and neck imaging

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Learning objectives

To outline the imaging techniques and normal findings of diffusion-weighted MRI (DWI) in the head and neck.

To describe the advantages and potential pitfalls of DWI in the head and neck compared with CT and conventional MRI.

To illustrate typical DWI imaging features of various head and neck pathologies, including; diagnosis of tumours of the aerodigestive tract, salivary glands and skull base, lymph node assessment, appearances of inflammatory and infectious diseases and imaging of the post-treatment neck.
Background

The principal imaging modalities for evaluating head and neck disease are MRI and CT. However, the diagnostic accuracy of these modalities is limited due to dependence on volumetric and morphological criteria (1, 2). Furthermore many head and neck pathologies share similar imaging features (3).

DWI is a fast and non-invasive functional MR technique, which can provide information regarding tissue microstructure and thus facilitate characterization of head and neck disease. DWI depicts the microscopic random or Brownian motion of constituent water molecules within biological tissues. The magnitude of this motion is characterized by apparent diffusion coefficient (ADC) value. Cellular packing, intracellular organelles, cell membranes and other macromolecules within the tissue, all act to restrict the random motion of water molecules. It is this variation in motion and redistribution of water molecules between tissue compartments that is reflected in DWI ADC values which, in turn helps to differentiate disease processes (4).

DWI has become a routine clinical application in imaging of the central nervous system (5, 6). Early evidence supports an equally important role for DWI in evaluation of the neck. In this educational exhibit, the role of DWI in diagnosis, prediction and monitoring of treatment response in head and neck disease will be discussed. The techniques and limitations of DWI acquisition are summarized and typical features of various head and neck pathologies are described.
Imaging findings OR Procedure details

Techniques for acquiring DWI images

There are several different techniques available for generating DWI images. However, turbo spin echo (TSE) (7) and single shot echo planar imaging (EPI) (8) remain the most frequently employed in current clinical practice. [Table 1.] shows the main advantages and disadvantages associated with each technique.

<table>
<thead>
<tr>
<th>Magnetic Sequence</th>
<th>Resonance Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Echo planar imaging | • Higher signal to noise ratio  
                     • Rapid image acquisition speed | • Artefact susceptibility  
                     • Geometric distortion |
| Turbo spin echo | • Reduced geometric distortion  
                     • Higher spatial resolution and fidelity | • Slower image acquisition  
                     • Reduced signal from non-restricting tissue e.g. fat, results in "noisy" ADC maps. |

[Table 1.] Advantages and disadvantages associated with commonly employed techniques for DWI acquisition.

The DWI nodes imaging protocol that is performed at our institution using a Philips Achieva 1.5T consists of:

- TR 7855
- TE 52
- 24 FOV
- 4mm slices with 0 gap
- 96 x 1.09 matrix size
- 4 acquisitions
- SPIR fat sat B0 and B600
- EPI factor 57.

The main limitation of DWI in the head and neck are associated artefacts (Fig. 1 on page 51). Artefacts result from continuous physiological motion from breathing and
swallowing but are also inherent to particular sequences. Susceptibility-induced artefacts are commonplace with EPI, particularly at air-soft tissue interfaces e.g. at the mucosal-airway interface and around sinuses. The relatively poor resolution of ADC maps, mean DWI data should always be interpreted in combination with other MRI sequences, e.g. T2-weighted or T1-weighted post-contrast, to delineate the area of interest accurately.

To date, DWI studies have been performed predominantly with a 1.5T magnetic resonance system. It has been reported that DWI in head and neck can be performed at a higher magnetic field (3T) (9). Unfortunately susceptibility artefacts are more frequent at higher field strengths.

**The normal diffusion anatomy of the neck**

Normal restricted diffusion is associated with the following anatomical structures within the neck:  

- Spinal cord and nerve roots (Fig. 2 on page 11 Fig. 3 on page 11 Fig. 4 on page 12)  
- Tonsillar tissue (Fig. 2 on page 11 Fig. 3 on page 11 Fig. 4 on page 12)  
- Lymph nodes (Fig. 5 on page 13).

Variable diffusion can be observed with the submandibular and parotid glands (Fig. 6 on page 14).

A pragmatic approach to interpretation of DWI in the head and neck entails comparison with internal frames of reference e.g. other lymph nodes or the spinal cord, which are present at every level of image acquisition.

**DWI in cervical lymph nodes**

Differentiation between inflammatory and metastatic lymphadenopathy often presents a diagnostic challenge with conventional imaging (10). Furthermore, FDG-PET and conventional MRI cannot reliably detect small tumour deposits in lymph nodes of normal size.

Although, threshold ADC values have been reported within the literature to differentiate between malignant and benign lymph nodes (11), DWI in isolation is not always helpful. For example in differentiating lymphomatous nodes from normal lymph nodes, the
Diffusion characteristics may be nearly identical and morphological grounds is often more useful.

DWI can be better in differentiating between malignant and benign lymph nodes when the pathological nodes show significantly different diffusion characteristics to normal nodes within the same patient. Often this is where the tumour has facilitated diffusion (Fig. 7 on page 15 Fig. 8 on page 16 Fig. 9 on page 17).

Malignant lymph nodes contain areas of necrosis and increased keratin (12, 13) resulting in altered water diffusivity. These changes are reflected in DWI, which may help to discriminate malignant from benign lymphadenopathy (Fig. 10 on page 18 Fig. 11 on page 19 Fig. 12 on page 20) (14, 15). Malignant nodes can exhibit lower ADC values than benign lymph nodes although some may demonstrate significantly higher ADC values than expected due to considerable necrosis or loose stromal matrix (16).

Despite the promising potential of DWI in detection of small malignant lymph nodes, low in-plane resolution of ADC maps and potential image artefacts can impact negatively on specificity and reproducibility of findings. For this reason, DWI should always be interpreted in conjunction with other MRI sequences to improve diagnostic accuracy.

**DWI in head and neck tumours; squamous cell carcinoma (SCC), nasopharyngeal carcinoma and lymphoma**

DWI has a role in characterization of head and neck tumours [Table 2.] (9, 15-17). A threshold ADC value of $1.22 \times 10^{-3}$ mm$^2$/s provided an accuracy of 86% sensitivity, 84% specificity and 91% for predicting malignancy. Representative MR and DWI images of a benign retropharyngeal cystic lesion (Fig. 13 on page 21 Fig. 14 on page 22 Fig. 15 on page 23 Fig. 16 on page 24), SCC of the head and neck (Fig. 17 on page 25 Fig. 18 on page 26 Fig. 19 on page 27 Fig. 20 on page 28 Fig. 21 on page 29), nasopharyngeal carcinoma (Fig. 22 on page 30 Fig. 23 on page 31 Fig. 24 on page 32 Fig. 25 on page 33) and lymphoma (Fig. 26 on page 34 Fig. 27 on page 35 Fig. 28 on page 36) are shown in the sidebar.

<table>
<thead>
<tr>
<th>Pathophysiology</th>
<th>Mean ADC value $(\pm 1 \text{ SD} \times 10^{-3} \text{ mm}^2$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benign solid lesions</td>
<td>High</td>
</tr>
</tbody>
</table>
1.14±0.20 (18)

Nasopharyngeal carcinoma  Lower
0.98±0.16 (18)

Lymphoma  Lowest
0.66±0.17 (15)

[Table 2.] (15, 17) Characteristic DWI features of benign solid lesions, SCC and lymphoma in the head and neck.

Highly or moderately differentiated SCC correlates with higher ADC values than those of poorly differentiated SCC (15, 16). This may be explained by a greater amount of liquefactive necrosis in the highly differentiated type.

**Characteristic features of salivary tumours**

Salivary gland tumours are relatively uncommon, accounting for less than 3% of all head and neck cancers. Conventional MRI has limited utility in differentiation of salivary gland tumours (20, 21). In contrast, significantly different DWI appearances, allows differentiation between pleomorphic adenomas (Fig. 29 on page 37 Fig. 30 on page 38), Warthin tumours (Fig. 31 on page 39 Fig. 32 on page 40 Fig. 33 on page 41 Fig. 34 on page 42) and mucoepidermoid carcinomas [Table 3.] (22, 23). Unfortunately, in some cases, there is considerable overlap of ADC values, and DWI alone may not be sufficient to discriminate between benign and malignant salivary gland tumours (24, 25).

<table>
<thead>
<tr>
<th>Pleomorphic adenoma</th>
<th>DWI appearance</th>
<th>ADC value</th>
<th>Pathophysiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyper - intense</td>
<td>High</td>
<td>Abundant fluid in glandular epithelial and stromal cellular components (26)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Warthin tumour</th>
<th>Hypo - intense</th>
<th>Low</th>
<th>Predominant lymphoid tissue (22, 25)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Mucoepidermoid carcinoma</th>
<th>Hypo - intense</th>
<th>Low</th>
<th>Enlarged nuclear:cytoplasmic ratio, hyperchromatism,</th>
</tr>
</thead>
</table>
Acinic cell carcinoma

Hypo-intense Low hypercellularity = reduced extracellular:intracellular volume and water diffusion space (19)

[Table 3.] (22, 25, 26) DWI features of benign and malignant salivary gland tumours.

**DWI appearances of infectious and inflammatory diseases in the neck**

The typical appearance of abscesses and necrotic lymphadenitis is reported to be hyper-intense on DWI with low ADC values (Fig. 35 on page 43 Fig. 36 on page 44 Fig. 37 on page 45 Fig. 38 on page 46) (27). In contrast necrotic nodal metastases appear hypo-intense on DWI with higher ADC values. These findings support previous studies where high protein component and viscosity of infective lesions impede water motion and thus result in lower ADC values (28).

**The role of DWI in differentiating between recurrent neck cancer and post-radiotherapy change**

Post treatment changes and recurrent neck tumour have very similar CT and MR imaging features and are notoriously difficult to differentiate (3). FDG-PET/CT may help to detect recurrent SCC (29), but inflammatory changes within the first 4 months following radiotherapy is an important confounding factor (30). In addition, biopsies performed post radiotherapy to identify residual/recurrent disease are often equivocal (31, 32) and there is reluctance to obtain multiple deep biopsy specimens incase of aggravating radio-necrosis (33).

Recurrent/residual tumours may be accurately differentiated from post-radiotherapy change by DWI both in the early (< 4 months) and late (> 4 month) period following treatment (Fig. 39 on page 47 Fig. 40 on page 48 Fig. 41 on page 49 Fig. 42 on page 50) [Table 4.] (34). A high sensitivity (94.6%), specificity (95.9%) and accuracy (95.5%) was reported for DWI in distinguishing between tumoral and nontumoral tissues. Furthermore, DWI yielded fewer false positives in comparison with CT or PET for both residual primary sites and lymphadenopathy (34).

<table>
<thead>
<tr>
<th>DWI appearance</th>
<th>ADC value</th>
<th>Pathophysiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrent/residual</td>
<td>Low signal intensity</td>
<td>Low</td>
</tr>
</tbody>
</table>
and hypercellularity = reduction in water diffusion space of extra- and intra cellular compartments (35)

Post radiotherapy change

High signal intensity

High cellularity, increased interstitial space, oedema/ inflammatory reaction/ submucosal fibrosis=increased interstitial water content & fewer barriers for diffusion (36)

Table 4.] (34-37) Characteristic DWI appearances of recurrent/residual disease vs. post radiotherapy change.

The role of DWI in monitoring treatment response and predicting outcome

The prognosis of patients with SCC of the head and neck remains poor despite aggressive therapeutic regimens and technological advances in surgery (38). Reliable and reproducible imaging markers capable of predicting tumour response would enable better selection of therapeutic strategy and improve overall clinical outcome. The potential of DWI to predict and detect early response to chemoradiation therapy in head and neck SCC has been previously studied [Table 5.] (39).

<table>
<thead>
<tr>
<th>Chemoradiation response</th>
<th>Pre-treatment DWI appearance</th>
<th>Change in mean ADC</th>
<th>Pathophysiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>Low signal intensity</td>
<td>Low (1.04 ± 0.19) to High</td>
<td>Response to cytotoxic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(± 1 SD x 10^3 mm^2/ s)</td>
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</table>
In this study, the observed changes in ADC values from pre-treatment to after 1 week of therapy demonstrated sensitivity of 86% and specificity of 83% for predicting treatment response in head and neck SCC (39).
Images for this section:

**Fig. 2:** Case 2: Coronal DWI B600 MIP demonstrating normal restricted diffusion associated with tonsillar tissue (yellow arrow), spinal cord (red arrow) and cervical lymph nodes (white arrows).

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Fig. 3: Case 2: Corresponding coronal T1 image demonstrating normal anatomy of tonsillar tissue (yellow arrow) and spinal cord (red arrow).

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Fig. 4: Case 2: Corresponding coronal T1 image demonstrating normal anatomy of cervical lymph nodes (white arrows).

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Fig. 5: Case 2: Axial DWI B600 showing normal restricted diffusion in cervical lymph nodes.
Fig. 6: Case 2: Axial DWI B600 showing normal restricted diffusion in left parotid gland.

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**Fig. 7:** Case 3: Axial T1+Gadolinium showing abnormal enhancement of right-sided lymph nodes.

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**Fig. 8:** Case 3: DWI B600 showing abnormal facilitated diffusion associated with right-sided lymph nodes.

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Fig. 9: Case 3: ADC map showing abnormal facilitated diffusion associated with right-sided lymph nodes. Fine needle aspiration confirmed recurrence of previously excised adenoid cystic carcinoma.

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**Fig. 10:** Case 4: Axial STIR heterogeneous appearance of enlarged right cervical lymph node.

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Fig. 11: Case 4: DWI B600 showing peripheral restricted diffusion associated with the enlarged right lymph node.

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**Fig. 12:** Case 4: ADC map of necrotic malignant node.

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Fig. 13: Case 5: Axial STIR of incidental benign retropharyngeal cystic lesion.

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**Fig. 14:** Case 5: DWI B600 of incidental benign retropharyngeal cystic lesion.

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**Fig. 15:** Case 5: ADC map of incidental benign retropharyngeal cystic lesion.

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Fig. 16: Case 5: Ultrasound image of retropharyngeal cystic lesion confirming anechoic composition.

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Fig. 17: Case 6: Axial T1+Gadolinium showing high grade SCC of right tonsil.

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**Fig. 18:** Case 6: DWI B600 showing restricted diffusion associated with high grade SCC of right tonsil.

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Fig. 19: Case 6: Corresponding ADC map showing restricted diffusion associated with high grade SCC of right tonsil.

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**Fig. 20:** Case 6: Axial DWI B600 from same patient showing necrotic nodal mass with associated mixed diffusion. Peripheral restricted diffusion allows extra-capsular spread to be distinguished from surrounding inflammatory reaction and oedema.

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**Fig. 21:** Case 6: ADC map showing necrotic nodal mass with associated mixed diffusion.

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**Fig. 22:** Case 7: Axial STIR showing large left sided nasopharyngeal carcinoma, which encases the left carotid artery.

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**Fig. 23:** Case 7: Axial T1 showing large left sided nasopharyngeal carcinoma, which encases the left carotid artery.

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Fig. 24: Case 7: DWI B600 of large left sided nasopharyngeal carcinoma. The mass lesion has a thick peripheral rind of tissue that shows marked restricted diffusion and central area of more facilitated diffusion.

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**Fig. 25:** Case 7: ADC map of large left sided nasopharyngeal carcinoma. The mass lesion has a thick peripheral rind of tissue that shows marked restricted diffusion and central area of more facilitated diffusion.

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Fig. 26: Case 8: Axial T1+Gadolinium image of diffuse large B-cell lymphoma centered on the right tongue base.

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**Fig. 27:** Case 8: DWI B600 of diffuse large B-cell lymphoma centered on the right tongue base. The lesion has marked restricted diffusion.

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Fig. 28: Case 8: ADC map of diffuse large B-cell lymphoma centered on the right tongue base. The lesion has marked restricted diffusion.

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Fig. 29: Case 9: Axial STIR showing high T2 signal associated with pleomorphic adenoma.

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Fig. 30: Case 9: ADC map showing characteristic facilitated diffusion associated with pleomorphic adenoma.

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Fig. 31: Case 10: Axial STIR of right-sided Warthin tumor with characteristic mixed low and high T2 signal.

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Fig. 32: Case 10: Axial T1 right-sided Warthin tumor with characteristic mixed low and high T1 signal.

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Fig. 33: Case 10: DWI B600 of right-sided Warthin tumor which demonstrates mixed diffusion facilitation and restriction.

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**Fig. 34:** Case 10: ADC map of right-sided Warthin tumor with characteristic mixed diffusion facilitation and restriction peripherally (red arrow).

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Fig. 35: Case 11: Axial STIR of bacterial tongue abscess post treatment for SCC. This was proven to be Staph. Aureas on biopsy.

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**Fig. 36:** Case 11: T1+Gadolinium image of bacterial tongue abscess post treatment for SCC. This was proven to be Staph. Aureas on biopsy. Note the central non enhancing area consistent with pyogenic abscess.

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Fig. 37: Case 11: DWI B600 of bacterial tongue abscess post treatment for SCC. This was proven to be Staph. Aureas on biopsy. Note the central restricted diffusion corresponds to the central non enhancing area consistent with pyogenic abscess.

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Fig. 38: Case 11: ADC map of bacterial tongue abscess post treatment for SCC. Note the central restricted diffusion corresponds to the central non enhancing area consistent with pyogenic abscess.

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Fig. 39: Case 12: Axial T1+Gadolinium from a patient with previous right tonsil SCC treated with radical neck dissection and chemoradiotherapy. There is new enhancing soft tissue in the peri-vertebral space.

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Fig. 40: Case 12: Axial STIR from a patient with previous right tonsil SCC treated with radical neck dissection and chemoradiotherapy.

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Fig. 41: Case 12: DWI B600 from a patient with previously treated right tonsil SCC. The new enhancing soft tissue in the peri-vertebral space is associated with restricted diffusion in keeping with extranodal recurrent tumour, rather than the effects of radiotherapy.

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Fig. 42: Case 12: ADC map from a patient with previous treated right tonsil SCC. The new enhancing soft tissue in the peri-vertebral space is associated with restricted diffusion in keeping with extranodal recurrent tumour, rather than the effects of radiotherapy.

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Fig. 1: Case 1: Axial DWI B600 showing significant artefact relating to dental implant.

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Conclusion

The majority of studies to date have employed a quantitative approach to DWI interpretation. Although, this is a robust method for validating research, subjective regions of interest, inter-observer variability and poor image quality due susceptibility artefacts limit the application of ADC values in clinical practice. A more pragmatic approach involves qualitative interpretation of DWI, within the clinical context and in combination with other MR sequences.

DWI presents an invaluable source of information for the radiologist interpreting imaging of the neck. Thorough knowledge of normal findings and limitations of the technique are vital in order to do so.
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