1. Preparations

In a DWI sequence diffusion sensitization gradients are applied on either side of the 180° refocusing pulse. The parameter "*b* value" decides the diffusion weighting and is expressed in s/mm^2. It is proportional to the square of the amplitude and duration of the gradient applied. Diffusion is qualitatively evaluated on trace images and quantitatively by the parameter called apparent diffusion coefficient (ADC). Tissues with restricted diffusion are bright on the trace image and hypo-intense on the ADC map.

The algorithms used in DWI acquisition make several assumptions, *e.g*., perfect field homogeneity, infinitely fast gradient changes, and perfectly shaped RF pulses, *etc*. However, with the available technology, the gradient coils can generate gradient magnitudes and switch rate of the order of 40 mTm^{-1} and 200 Tm^{-1}·s^{-1} respectively. Such discrepancies limit DWI accuracy and result in lower image quality and image artifacts[74]. Major limitations of DWI are experienced in body imaging and are largely because of it being an EPI sequence[59,60]. DWI is susceptible to various artifacts, *e.g*., T2 shine through, T2 black out, ghosting, blurring and distortions. Tissues with very long relaxation times might tend to retain signal on high *b* value images. This is known as "T2 shine through" effect. Corresponding bright signal on ADC map by such lesions helps to differentiate it from restricted diffusion, which appears dark on ADC maps. T2 blackout effect is the term used for low signal on ADC map due to lack of enough water protons and not due to restricted diffusion. Low signal on T2 weighted fat saturated images is the diagnostic sign for such an effect.

Another bothersome limitation of DWI is the questionable reproducibility of ADC values. ADC values can vary even with the use of same MR system. Such variability has been attributed to the inherent low SNR, artifacts and distortions related to SS EPI sequence. Rapid on/off transition of diffusion gradients during EPI sequence causes eddy-current related distortions resulting in image degradation and systemic errors in ADC calculations.

Table 1
Technical Requirements of Diffusion MR Imaging Techniques

Technique and Reference	3.0 T and High Gradient Strength Capabilities	No. of Gradient Directions	Maximal Gradient Strength (sec/mm2)	Acquisition Time (min)*	Post processing	Display
Diffusion weighted imaging	Optional	1	≤1000	1–3	None	Gray-scale sections

2. Usefulness compared to other modalities and sequences

MRI provided an excellent contrast resolution not only from tissue (proton) density, but also from tissue relaxation properties. After initial focus on T1 and T2 relaxation properties researchers explored other methods to generate contrast

exploiting other properties of water molecules. Diffusion weighted imaging (DWI) was a result of such efforts by researchers like Stejskal, Tanner and Le Bihan[2] [Le Bihan D. Diffusion MRI: what water tells us about the brain. EMBO Mol Med. 2014;6:569–573.].

2.1. Diffusion-weighted MR Imaging

Diffusion-weighted MR imaging is the simplest form of diffusion imaging. A diffusion-weighted image is one of the components needed to reconstruct the complete probability density function as in diffusion spectrum imaging. A diffusion-weighted image is the unprocessed result of the application of a single pulsed gradient SE sequence in one gradient direction, and it corresponds to one point in q-space. Even though such an image is rather simple, it does contain some information about diffusion. In Figure 13, the left splenium of the corpus callosum appears bright, whereas the right splenium appears dark. In regions such as the right splenium, where the main diffusion direction is aligned with the applied diffusion gradient, the intensity of the signal is markedly decreased, and the region therefore appears darker on the image. In the ventricles, diffusion is free and substantial in all directions, including the applied gradient direction, and therefore the entirety of the ventricles appears dark. Despite its simplicity, diffusion-weighted imaging is routinely used in investigations of stroke (15). Indeed, in acute stroke, the local cell swelling produces increased restriction of water mobility and hence a bright imaging appearance due to high signal intensity in the area of the lesion. The benefit of diffusion-weighted imaging is that the acquisition time is short, since only one image is needed.

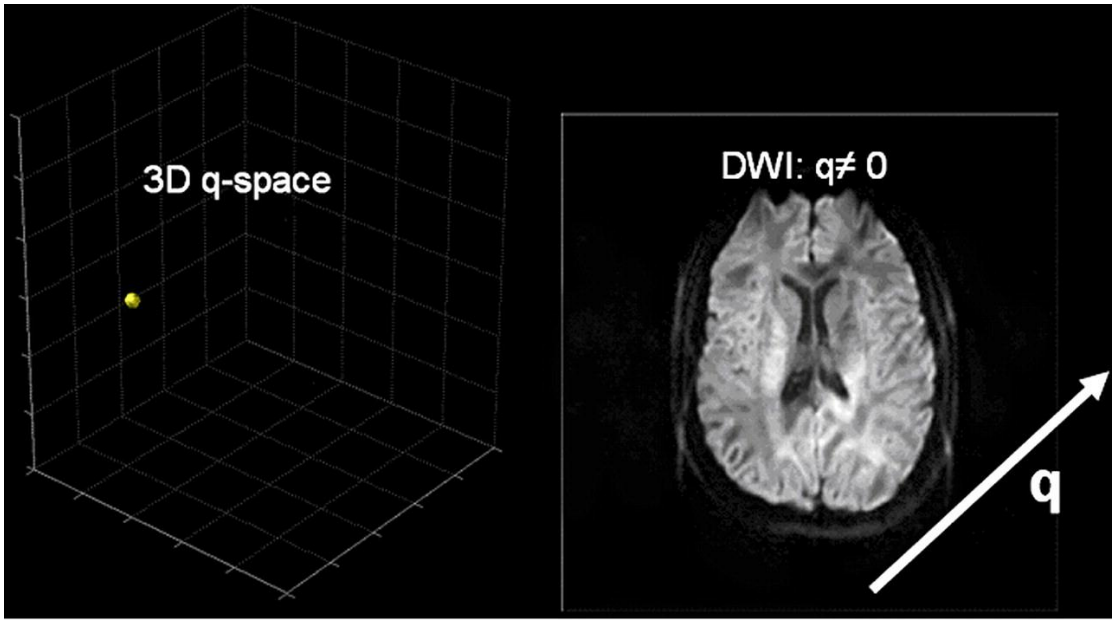

Figure 13. Diffusion-weighted image (right) from signal sampling at a single point in 3D q-space (left). Brain areas where diffusion is intense in the direction of the applied gradient ($\vec{q}$) appear darker because of a decrease in the measured signal that results from de-phasing.

- DWI may be useful to demonstrate persistent or progressive tumor despite the lack of contrast enhancement. Pseudo-progression is seen in the setting of edema associated with the inflammatory response rather than progression of the true tumor.
- DW-MRI has been applied in head and neck neoplasms
- DWI can be used for distinguishing malignant from benign and inflammatory lung lesions and helps in differentiation of small cell cancers (SCLC) from non-small cell cancers (NSCLC).
- DWI can easily distinguish benign renal cysts from solid neoplasms
- The exquisite sensitivity of DW MRI to microstructural changes enables us to detect the abnormalities much before changes on conventional images.
- DWI improves the diagnosis of cervical and endometrial tumors[62]. DW MR imaging is especially useful for accurate determination of the depth of myometrial invasion in patients with endometrial cancer

Hepatobiliary pancreatic cancers

DWI is helpful in focal liver lesion detection and characterization and can be used as an alternative to Gadolinium enhanced MRI in patients with renal dysfunction. Clinical applications of DW MRI include treatment response monitoring and prognostication in patients receiving systemic and focal ablative therapies for hepatic and pancreatic malignancies[43-46]. Hardie et al[47] compared the utility of DWI in detection of liver metastases. They reported that DWI has 66.3% sensitivity compared to 73.5% for CE-MRI and hence it can serve as a useful alternative for this purpose. DW MR imaging has been investigated in diffuse hepatic parenchymal disease such as non-alcoholic fatty liver disease and hepatic fibrosis.

Bowel disorders

DWI is useful for detection of colorectal cancer, nodal and hepatic metastases and prediction of response after radio-chemotherapy for locally advanced rectal cancer[50-52]. DWI detects therapy-induced modifications in lesion vascularity during anti-angiogenic therapy before significant changes in size are evident[53,54]. DWIBS has been reported a useful tool in detection of nodal metastasis of colorectal cancer[55]. In addition to its utility in abdominal malignancies, DWI has also been found useful in inflammatory bowel disease. Qi et al[56] reported that DWI combined with MR enterography (MRE) has higher diagnostic accuracy (92%) than MRE alone (79%) for disease activity. It has also been found to be useful in detection and characterization of extraintestinal manifestations and complications[57]. Use of DWI with MR enterography improves mesenteric and small bowel tumor detection compared to unenhanced MR-enterography.

As there are a lot of techniques of diffusion MR, we can list them as following:

1. Diffusion-weighted MR Imaging
2. Trace and ADC imaging
3. Diffusion tensor imaging
4. q-Ball imaging
5. Diffusion spectrum imaging

Hence we are going to clarify in **table 1** the advantages and drawbacks of this various techniques,

Technique	Information Obtained	Advantages	Drawbacks
Diffusion-weighted imaging	Diffusion measurement in one direction	Short acquisition time, no post processing, images easy to interpret. Examination well tolerated by patients. Adequate hardware capabilities readily available.	Provides unidirectional diffusion measurement only, limited information. Voxel intensity is not a natural physical unit but a measure of restriction.
Trace and ADC imaging	Estimated diffusion coefficient	Short acquisition time, nearly no (or automated) post processing, images easy to interpret. Voxel intensity has physical meaning. Examination well tolerated by patients. Adequate hardware capabilities readily available.	Hypothesis based (hypothesis not always true). Limited information (no measurement of orientation or anisotropy)
Diffusion tensor imaging	Estimated diffusion tensor	Short acquisition time, some post processing required (automated on recent imaging systems). Provides information about diffusion orientation and anisotropy. Examination well tolerated by patients. Adequate hardware capabilities readily available.	Hypothesis based (hypothesis not always true). Does not provide accurate map of complex fiber architecture. Tractography results are vulnerable to severe artifacts.
q-Ball imaging	Estimated map of orientation distribution function values	Feasible with reasonable acquisition time. Provides information about diffusion orientation and anisotropy, accurate depiction of fiber crossings. Examination tolerated by most patients.	Hypothesis based. Although results seem correct in important brain areas, accuracy is not guaranteed in all brain regions. Further validation is required. Hardware requirements are high.
Diffusion spectrum imaging .	Full 3D diffusion probability density function map, true 6D images	Principle based, hypothesis free, has already received theoretical and practical validation. Provides accurate depiction of fiber crossings with a specific angular resolution. Maps the entire field of diffusion, providing 6D data and increasing the possibility of quantitation. Provides diffusion tensor information.	Hardware requirements are high, and acquisition time is comparatively long. Whole-brain studies were not tolerable for patients. Recent improvements in hardware and imaging techniques have made shorter acquisition times possible, allowing future patient studies.

Table 1
Advantages and Drawbacks of Diffusion MR Imaging Techniques