

# DIFFUSION-WEIGHTED MRI OF ISCHEMIC STROKE

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## INTRODUCTION

Diffusion-weighted magnetic resonance imaging (DW-MRI) is a highly sensitive tool for the detection of early changes in water diffusion that characterize many brain pathologies, including acute ischemic stroke.<sup>1,2</sup> These changes represent variations in the random motion of water molecules in tissues. They are expressed, in diffusion-weighted images, as changes in MRI signal intensity or as variations in the apparent diffusion coefficient (ADC) of water.

Acute brain lesions like ischemic stroke are associated with reduced water diffusion, and they can be detected as bright areas of signal hyperintensity in DW images, or as dark areas of signal hypointensity in ADC maps.<sup>3-5</sup>

While it takes hours to reach a diagnosis of ischemic stroke with conventional MRI, DW imaging allows detection of the disease within minutes.<sup>6,7</sup> Diffusion-weighted MRI also detects lesions not usually identifiable with conventional MRI,<sup>1,2</sup> and can discriminate between new and old strokes<sup>1</sup> as well as between acute and chronic ones.<sup>8</sup>

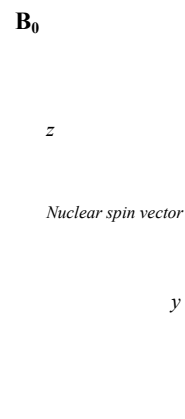
An accurate and early diagnosis of ischemic stroke is critical in ensuring patients receive prompt treatment, which, in turn, improves their chances of survival and increases their likelihood of recovery. This article provides practicing technologists with insight into the use of diffusion-weighted imaging as a method that is more effective than conventional MRI for the detection of acute ischemic stroke. It first explains the physics of magnetic resonance and describes the diffusion-weighted technique. It then looks at the pathophysiology of stroke and reviews the research supporting the use of DW-MRI in the early detection of acute ischemic injuries as a means to improve patient outcome.

## THE PHYSICS OF MRI

About two-thirds of the human body is made up of water. Each molecule of water consists of two hydrogen atoms and one oxygen atom. So, hydrogen is the most abundant element in our tissues and organs, and this fact is what makes MRI possible.

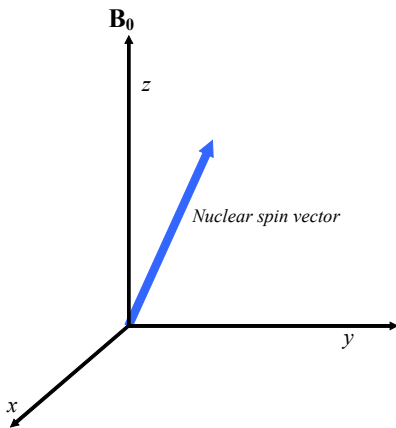
Deep inside each atom of hydrogen is a positively charged particle called a proton. This can be imagined as a tiny bar-magnet randomly oriented in space. It is referred to as *nuclear spin* and is represented as a three-dimensional vector in an x, y, z coordinate system. The nuclear spin vector is the quantity being imaged by MRI.<sup>9</sup>

In the presence of a magnetic field, such as that produced when a patient is placed inside a scanner, the hydrogen protons (i.e., the nuclear spins) of the body tend to align in the direction of the magnetic field. Let's call this field  $B_0$  and assume that it is directed along the z axis. Then, the hydrogen protons of the patient's body will point along the z axis (Figure 1).<sup>9</sup> As a result, the transverse components of the spin vector—that is, the components in the xy plane, which is perpendicular to the magnetic field—are zero. The nuclear spin is said to be in a fully relaxed state (i.e., no excitation is present). Because there are no transverse spin components, there is no MRI signal.<sup>9</sup>



**FIGURE 1.** Proton (i.e., nuclear spin vector) aligned in the direction of the magnetic field ( $B_0$ ) generated by the scanner. There are no transverse spin components, and, consequently, there is no MRI signal.

On the other hand, if the nuclear spin is excited by means of the application of a radio-frequency (RF) field, it will start rotating around the z axis. The spin vector is thus tilted out of alignment with the main magnetic field  $B_0$  and now has transverse components different from zero (Figure 2). This state is referred to as *excitation*. The transverse spin components can generate an MRI signal.<sup>9</sup>



**FIGURE 2.** Hydrogen proton (nuclear spin vector) tilted out of alignment with the main magnetic field ( $B_0$ ) following application of a radio-frequency field. The transverse spin components are different from zero. An MRI signal can now be generated.

## DIFFUSION-WEIGHTED MRI

### DIFFUSION-WEIGHTED IMAGES

Magnetic resonance images, including diffusion-weighted ones, can generically be described as displays of differences in MRI signal intensity, and it is these differences that produce the contrast needed for anatomic imaging and tissue characterization. However, different MRI techniques are based on different types of contrast. So, for example, T1- and T2-weighted MRI use contrast in relaxation times, whereas functional MRI uses blood-oxygen-level-dependent contrast.<sup>10</sup>

In diffusion-weighted MRI, image contrast is produced by variations in the rate of water diffusion, namely the random, translational, and temperature-dependent movement of water molecules in biological tissue.<sup>11,12</sup> In reality, because of the presence of structures like cell membranes, water molecules do not move completely at random in biological tissues. For this reason, water diffusion is referred to as *apparent diffusion*.

How are diffusion-weighted images obtained? The key is to generate spatially dependent variations of the main, static magnetic field  $B_0$ . Such variations are achieved by means of auxiliary magnetic fields, called *gradient fields*, which are superimposed upon the main magnetic field and applied along the x, y, and z coordinate axes. Gradient

fields are applied for a short time, which produce what is referred to as a *gradient pulse*. They have their magnetic component always aligned with the main magnetic field—in the z direction—but their strength, which refers to the rate at which their magnetic field changes with distance, varies spatially along one particular direction—x, y, or z—in a linear manner.<sup>9</sup>

Diffusion-weighted images are obtained by adding two strong diffusion-sensitizing magnetic field gradient pulses. The gradient pulses are added after nuclear spin excitation has occurred but before the acquisition of data. As a result, imaging is sensitized to water diffusion (i.e., motion) in the direction of the additional applied gradients. These lead to an attenuation of the signal's intensity along the axis to which they are applied. In the absence of artifacts, such attenuation is directly proportional to water diffusion—that is, the higher the water diffusion of the brain region under investigation, the greater the signal attenuation and the darker the image.<sup>13</sup>

Note that brain regions of ischemic infarction are characterized by reduced water diffusion, due to reduced blood flow. Therefore, they appear in diffusion-weighted images as hyperintense, bright areas.<sup>13</sup>

The magnitude of water signal attenuation in diffusion-weighted MRI depends on two factors: the extent of the translational movement of water molecules, and the diffusion weighting. The latter varies according to the strength, duration, and separation time of the gradient pulses. The sensitivity to water diffusion is defined by the gradient factor  $b$  (sec/mm<sup>2</sup>).

So, we have seen that the addition of magnetic field gradient pulses results in image sensitization to water motion and consequent attenuation of the signal, in the direction to which the gradient pulses are applied:

**gradient pulses → image sensitization → signal attenuation**

This fact means that, by applying the magnetic field gradients in different directions, it is possible to study how water diffusion changes along different axes. For instance, if the gradient pulses are applied in all three directions, then sensitization occurs along the three axes—x, y, and z—and a global evaluation of the way in which water diffusion varies in a certain tissue is obtained. On the other hand, if the gradient pulses are applied in only one direction, image sensitization occurs along that particular axis, for which water diffusion variations can be evaluated. This is useful to study *anisotropy of water diffusion*—a phenomenon whereby water diffusion in a biological tissue is greater along one particular direction. The cortical grey matter of the brain is an example. The presence of radially-oriented neocortical pyramidal neurons results in anisotropy of water diffusion. This can be studied in diffusion-weighted imaging where only the x direction has been sensitized to water motion by means of the application of gradient pulses.<sup>13</sup>

## DIFFUSION-WEIGHTED IMAGING MODALITIES

One problem with diffusion-weighted imaging is that it is highly sensitive to the continuous bulk motion of brain tissue, and this is a frequent cause of artifacts like ghosting and blurring.<sup>14</sup> This problem can partly be overcome using fast imaging. Thus, diffusion-weighted images are obtained either with a high-field (1.5-Tesla) echo-planar imaging (EPI) system with high gradients (e.g., 25mT/m) or with a fast (turbo) sequence on a system with standard gradients (e.g., 9mT/m).<sup>11</sup> Diffusion-weighted single-shot EPI, which uses only one nuclear spin excitation per image, allows more data to be collected with each spin excitation than is possible to collect with conventional spin-echo (SE) imaging. This significantly shortens MRI times—typically, EPI images are acquired in less than 100 ms—and virtually eliminates motion-related artifacts.<sup>13,15</sup>

However, with diffusion-weighted single-shot EPI, the image acquisition matrix cannot be larger than  $128 \times 128$ , which results in limited resolution. Other problems may occur and may lead to artifacts—such as image distortion and signal loss—due to susceptibility differences,<sup>16</sup> T2 relaxation, and main field inhomogeneities.<sup>17</sup> Furthermore, transient eddy currents induced by gradient switching produce additional magnetic fields that may cause spatial distortion.<sup>18</sup>

Another way to obtain diffusion-weighted images is to use multishot EPI—also called segmented echo-planar imaging (SEPI). The term *multishot* refers to the fact that data are collected with several RF excitations.<sup>19</sup> Although there may be some ghosting, higher sensitivity to motion-induced artifacts, and phase errors, these can partly be avoided with navigator echo phase corrections. Specifically, these allow attenuation of phase errors due to motion, magnetic field inhomogeneities, and gradient timing errors.<sup>16</sup>

Diffusion-weighted images can also be obtained with fast (turbo) spin-echo imaging (FSEI). This technique is similar to EPI, in that data are collected with one acquisition. However, in FSEI, the initial  $90^\circ$  excitation pulse is followed by a train of  $180^\circ$  refocusing pulses, each of which produces a detectable spin echo.<sup>20,21</sup> Therefore, although data are acquired within one repetition time, the need for RF refocusing pulses implies that fast spin-echo imaging takes longer than echo-planar imaging. However, they make the sequence less susceptible to field inhomogeneities. The likelihood of spatial distortion, fat shift, and signal loss are also reduced.

## ADC MAPS

Besides images, another way to present diffusion data is with maps of the apparent diffusion coefficient (ADC) of water. These are derived from diffusion-weighted images according to the method described by Le Bihan et al.<sup>22</sup> For a standard DW-MR sequence,

the apparent diffusion coefficient of water is calculated from the following equation<sup>3;23,24</sup>:

$$S(b) = S_0 \exp(-bD^*) \quad (1)$$

Where

- $S(b)$  is the measured signal intensity in the image with diffusion weighting (i.e., diffusion-gradient attenuated pixel intensity; diffusion-weighting =  $b$ );
- $S_0$  represents the measured signal intensity in the image without diffusion weighting (i.e., unattenuated pixel intensity; diffusion-weighting = 0);
- $b = \gamma^2 \int_0^{TE} (\int_0^t G_D(t') dt')^2$  where  $dt$  is the gradient factor<sup>25</sup> ( $G_D(t)$  represents the effective diffusion gradient as a function of time, and  $\gamma$  is the gyromagnetic ratio); and
- $D^*$  is the apparent diffusion coefficient of water (ADC).

By fitting the image data into equation (1) it is thus possible to calculate the ADC value for each pixel and compute ADC maps.

It is important to note, however, that equation (1) refers to signal attenuation in samples with just one compartment.<sup>23</sup> Therefore, for brain tissues, which consist of at least two different compartments—intracellular and extracellular spaces—ADC maps need to be calculated from the following equation<sup>23</sup>:

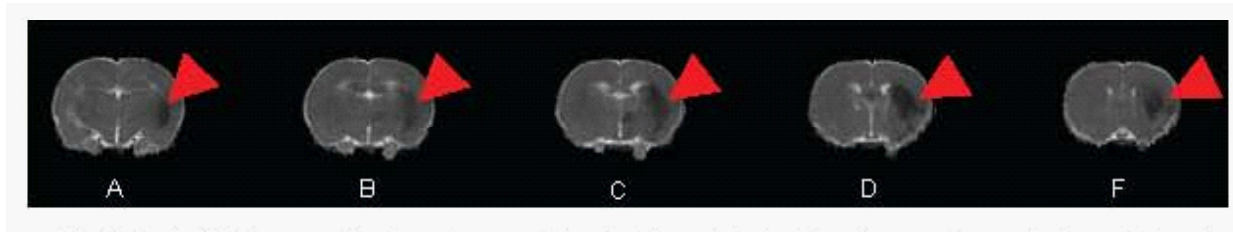
$$S(b) = S_0 [f_{ECS} \exp(-bD_{ECS}) + f_{ICS} \exp(-bD_{ICS})] \quad (2)$$

Where

- $f_{ECS}$  is the fast extracellular diffusing fraction of water;
- $f_{ICS}$  is the slow intracellular diffusing fraction of water; and
- $D_{ECS}$  and  $D_{ICS}$  are the ADCs of the fast and slow fractions of water, respectively.

Diffusion-weighted MRI is performed with several different  $b$  values in order to obtain maps of pure water ADC values, where there is no contribution of T1, T2 and proton density contrast.<sup>5</sup>

Figure 3 shows examples of ADC maps of adjacent coronal brain slices of rat, at two hours after middle cerebral artery occlusion (MCA-O). The hypointense, dark areas represent the ischemic injury with restricted water ADC.<sup>5</sup>



**FIGURE 3.** ADC maps of adjacent coronal brain slices of rat, at two hours after embolic unilateral MCA-O. The site of acute ischemic injury, which corresponds to a reduced water ADC, appears as a hypointense, dark area (red arrows) and is more evident in images C to F. (Photo courtesy of Dr. Ivo Tiebosch and Dr. Mark Bouts of the Image Sciences Institute, University Medical Center Utrecht, The Netherlands).

## THE PATHOPHYSIOLOGY OF ISCHEMIC STROKE

Stroke is defined as an “acute neurologic dysfunction of vascular origin” characterized by sudden (i.e., within seconds) or rapid (i.e., within hours) onset of signs and symptoms.<sup>26</sup> *Symptoms* are manifestations of stroke that only the patient can describe, such as headache, confusion, or pain, whereas *signs* are manifestations that the doctor can also observe, like slurred speech or a lower eyelid. Signs and symptoms vary from patient to patient depending on the part of the brain that has been affected.<sup>26</sup>

Only 15% of all strokes are *hemorrhagic*, that is, caused by a blood vessel that breaks and leaks into the brain. Approximately 85% are *ischemic*, and are caused by the blockage of a blood vessel to the brain. As a result, blood flow to a certain brain region is interrupted, and cells receive insufficient amounts of oxygen and glucose to continue to function.<sup>27</sup> Because the brain cannot store glucose, tissue destruction follows quite rapidly.<sup>28</sup>

Ischemic strokes can be of two main types: *thrombotic* or *embolic*. Thrombotic strokes, also referred to as *thrombosis*, are caused by blood clots that develop in intracranial and extracranial arteries. They are the most common type of ischemic stroke, occurring in about 45% of cases. Atherosclerotic plaques are a characteristic pathological feature of thrombosis. Embolic strokes, on the other hand, occur as a result of blood clots that travel to the brain from a distant location in the body. Only about 25% of ischemic strokes are embolic. Not just blood clots can embolize to various locations in the central circulation, but also fat or air.<sup>27</sup>

The severity and outcome of an ischemic injury depend on several factors. In general, the damage is less severe for ischemic events that occur slowly or have short duration. An efficient collateral arterial system, especially between the vertebral and carotid arteries through the circle of Willis, normoglycemia, and a low body temperature are also associated with less severe outcomes.<sup>29</sup>

As mentioned, when an ischemic stroke occurs, insufficient blood reaches the brain. This insufficiency affects the delicate balance of environmental variables (e.g., pH, temperature, and oxygen and ion concentrations)

that allows the brain tissue to function at its best, and it starts, within seconds to minutes, what is known as the *ischemic cascade*. The ischemic cascade is a complex series of biochemical changes that occur at the cellular level. It affects both neurons and glia.<sup>27</sup>

Initially, the decrease in cerebral blood flow, which in normal conditions is about 60 mL/100g/min, is compensated for by vasodilation and increased oxygen and glucose extraction. This allows for some neuronal activity to continue. However, when the blood flow falls below 20 mL/100g/min, the electrical communication among neuronal cells stops. This is known as the *penumbra phase*. Cerebral blood flow values below 10 to 15 mL/100g/min trigger the ischemic cascade, and irreversible neuronal death occurs.

## EDEMA

Ischemia induces edema, or swelling of the brain, which develops within minutes of the insult, and is a leading cause of death and morbidity after stroke. Ischemic edema is defined as an increase in brain tissue water content and is caused by an altered distribution of sodium and potassium ions in the intracellular and extracellular space, as a result of a dysfunction of the cell membrane  $\text{Na}^+/\text{K}^+$  ion pump. This causes sodium to move from the extracellular to the intracellular space—a phenomenon known as *anoxic depolarization*—which leads to the loss of ion homeostasis and promotes early intracellular water accumulation. This initial phase is called *cytotoxic edema*. Subsequently, water also accumulates in the extracellular space together with serum proteins. This stage is known as *vasogenic edema*.<sup>30,31</sup>

The hyperintensity observed in diffusion-weighted images after ischemic stroke reflects the decrease in ADC associated with cytotoxic edema formation due to the failure of the sodium pump.<sup>9</sup> A decrease in the apparent diffusion coefficient of water also characterizes the penumbra that surrounds the ischemic core. However, in the penumbra, the ADC is reduced to a lesser extent than in the center of the infarction.<sup>9</sup>

## CELL DEATH

Characteristic of ischemia is the build up, in the extracellular space, of the neurotransmitters glutamate and aspartate—a phenomenon known as *excitotoxicity*. This leads to the opening of membrane calcium channels. Consequently, calcium accumulates in the intracellular space where it activates enzymes, with subsequent release of cytokines, which results in damage to neuronal cells.<sup>32</sup>

These die by one of two mechanisms: *coagulation necrosis* or *apoptosis*. Coagulation necrosis usually develops six hours after the ischemic insult, and can take up to 24 hours to complete. Neuronal death occurs as a result of damage to the plasma membrane. The neuronal cell first swells and then contracts. Its nucleus condenses and death occurs without provoking any inflammatory response. Apoptosis—also called programmed cell death—normally starts one hour after the ischemic insult. The nucleus is the first to degenerate, and damage to the plasma membrane occurs only in the latest stages of the death process. Research shows that both necrosis and apoptosis are activated in the same ischemic neuronal cell and that the type of death is determined by the speed of the two processes.<sup>33</sup>

Studies conducted in recent years on the ischemic cascade have contributed to a better understanding of the events involved, which has provided important information about treatment possibilities that may increase the likelihood of recovery. For instance, the results of these studies show that the ischemic cascade can be stopped with both pharmacological and non-pharmacological interventions, and that the penumbra surrounding the core of the ischemia is potentially salvageable.<sup>27</sup> Specifically, neuronal damage in the penumbra can be partly or completely reversed if treatment with recombinant tissue plasminogen activator (rt PA) is given within a time window of about three hours after the onset of symptoms.<sup>34</sup>

Without treatment, some areas of the ischemic penumbra recover spontaneously (benign oligemia), but others progress to irreversible neuronal damage. So, it is important to be able to discriminate between the infarcted core and the ischemic penumbra as soon as possible, so that patients suitable for treatment can be identified.<sup>34</sup>

## RATIONALE FOR USE OF DW-MRI IN ISCHEMIC STROKE

As described, brain ischemia quickly leads to the formation of edema. Now, studies on animal stroke models show that edema is associated with significant reductions in the apparent diffusion coefficient of water, and that these occur well before they can be detected by conventional T2-weighted spin-echo MRI.<sup>35</sup> We have also seen that changes in the apparent diffusion coefficient of

water can be identified with diffusion-weighted imaging. Therefore, DW-MRI allows for a faster detection of ischemic stroke. Specifically, diffusion-weighted imaging can identify cerebral ischemia within minutes, whereas standard MR sequences require three to four hours.

These findings have been confirmed in clinical trials aimed at investigating the prognostic superiority of diffusion-weighted methods over conventional MRI. In one study, DW-MRI detected six ischemic lesions, on a total of 103 images, not seen on T2-weighted scans. It also allowed for the identification of new ischemic lesions from old strokes.<sup>1</sup> In another study, 98% of acute cerebral ischemic lesions from 42 patients were identified with the diffusion-weighted technique, compared to 91%, 80%, and 71% detected with fluid-attenuated inversion recovery-weighted, proton density-weighted, and T2-weighted MRI, respectively.<sup>2</sup>

Subsequent research conducted on a sample of 19 patients with severe ischemic lesions has provided further evidence of the clinical superiority of diffusion-weighted MRI, as compared to conventional imaging methods alone, in terms of predicting the clinical outcome of stroke patients. When performed within six hours of the onset of symptoms, not only did DW-MRI allow for more-accurate localization of the lesions, it was also significantly more accurate than T2-weighted MRI at predicting whether there would be no, partial, or complete recovery.

Clinical outcome was accurately predicted in 92% of cases with diffusion-weighted imaging and in 33% of cases with T2-weighted imaging.<sup>36</sup> More recently, a large study of 691 patients admitted to the emergency department with suspected acute stroke found that diffusion-weighted imaging had an accuracy of 97% in identifying ischemic lesions, whereas conventional MR imaging (T1-weighted and T2-weighted) showed an accuracy of about 64%.<sup>37</sup> In the study, magnetic resonance examinations were performed on a 1.5-Tesla Signa Magnet (General Electric Medical Systems). Diffusion-weighted images were obtained with single-shot EPI using the following protocol:

- Repetition time: 6,000 ms
- Echo time: 118 ms
- Field of view: 40 × 20 cm
- Matrix size: 256 × 128 pixels
- Section thickness: 6 mm, with 1-mm gap
- Gradient strength: 14 mT/m
- *b* values: 1,221 and 4 sec/mm<sup>2</sup> (six gradient directions and three signals acquired)
- Image acquisition time: 126 seconds

Notably, the superiority of diffusion-weighted imaging over T1- and T2-weighted MRI was observed for scans

taken up to 12 hours after admission to the emergency department. However, it was greatest when imaging was performed within six hours of presentation.<sup>37</sup>

The advantages of DW imaging in accurately identifying acute ischemia have been demonstrated also by research conducted on conventional MRI methods other than T1- and T2-weighted imaging. In one study of 52 stroke patients, diffusion-weighted images performed within 48 hours after onset of symptoms allowed for the detection of a greater number of lesions than proton density-weighted images and fluid-attenuated inversion recovery images.<sup>38</sup> In this case, single-shot echoplanar DW images were obtained with the following protocol:

- Repetition time: 6,000 ms
- Echo time: 110 ms
- Field of view: 24 cm
- Matrix size: 256 × 256 pixels
- Section thickness: 5 mm, with 2.5-mm gap
- *b* values: 0 and 849 sec/mm<sup>2</sup> (six gradient directions and three signals acquired)

For one of the patients in the study, scans were taken seven hours after the onset of left arm discoordination. T2-weighted, proton density-weighted, and fluid-attenuated inversion recovery (FLAIR) scans showed no ischemic lesion. This lesion was visible only in diffusion-weighted images and in corresponding ADC maps.

A further advantage of diffusion-weighted MRI has been highlighted within another study, showing that ischemic lesions in DW images can be detected with a high degree of reliability not only by radiologists experienced in stroke imaging, but also by novices.<sup>39</sup> These results are of particular significance, given that novice radiologists are, in most cases, the first to examine patients with suspected stroke admitted to emergency departments.

However, DW-MRI also has some intrinsic limitations. For example, it is not possible with DW imaging alone to distinguish between normal brain regions that have not been affected by the ischemia and the penumbra, because the differences in ADC are too small to be picked up with the diffusion-weighted method.<sup>36</sup> To overcome this problem, diffusion-weighted imaging is combined with perfusion-sensitive MRI, which uses injected contrast material. The mismatch between the images obtained for the same area with the two methods is thought to correspond to the penumbra.<sup>34</sup>

Recently, there has been growing interest in investigating the accuracy of diffusion-weighted images obtained using scanners with magnets of different strengths. The results of the studies discussed above are based on DW images generated with 1.5-T MRI units. These are used in hospitals as the clinical standard. However, an increasing

number of departments are now replacing 1.5-T scanners with 3.0-T ones. With a magnetic field that is twice the strength, they are considered more effective in the detection of ischemic stroke. However, the latest of a series of studies comparing 1.5-T and 3.0-T diffusion-weighted MRI seems to suggest the contrary. In a sample of 135 patients with acute ischemic stroke and 34 healthy controls, 1.5-T DWI was more accurate than 3.0-T DWI. Diffusion-weighted MRI at 1.5-T failed to detect a stroke in less than one in 100 cases, whereas diffusion-weighted MRI at 3.0-T missed 1 in 16 cases.

## CONCLUSION

Diffusion-weighted images are displays of signal intensities primarily dependent on water motion, which produces image contrast. They are generated by adding two strong diffusion-sensitizing magnetic field gradient pulses to the MRI pulse sequence. This process results in the imaging being sensitized to water motion in the direction of the applied gradients, whose strength, duration, and separation time determine the diffusion weighting of the images, which are characterized by the gradient factor *b*.

Shortly after an ischemic stroke, a decrease in water diffusion occurs, which becomes apparent in DW images as hyperintense, bright areas. From diffusion-weighted images, which are obtained using different values of the gradient factor *b*, maps of pure apparent coefficient (ADC) of water can be calculated, where there is no contribution of T1, T2, and proton density contrast. In ADC maps, acute ischemic lesions appear as hypointense, dark areas.

Studies demonstrate that diffusion-weighted imaging is a valuable tool, for both expert and novice radiologists, in the early diagnosis of ischemic stroke, and that it has prognostic superiority over conventional MRI. It can detect lesions within minutes instead of hours, and it has greater accuracy. It can also differentiate new strokes from old strokes and discriminate between acute and chronic ischemia.

Potential disadvantages of DW-MRI include its ineffectiveness at identifying the penumbra and the possibility of image artifacts due to the bulk motion of brain tissue. However, the former problem can be resolved by combining diffusion-weighted imaging with perfusion imaging, whereas artifacts can be reduced if diffusion-weighted images are obtained with fast imaging modalities, such as single-shot echoplanar imaging (SSEPI), segmented echoplanar imaging (SEPI), and fast spin-echo imaging (FSEI). These consistently shorten imaging times and, consequently, reduce the occurrence of motion artifacts.

According to the latest research, DW images obtained with 1.5-T scanners allow for greater accuracy in the detection of acute ischemic strokes than images generated with 3.0-T units.<sup>40</sup>

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## DIFFUSION-WEIGHTED MRI OF ISCHEMIC STROKE POST TEST

Expires: October 15, 2012 Approved for 1 ARRT Category A Credit

1. **MRI is possible because the human body is mostly made of**
  - a. oxygen.
  - b. calcium.
  - c. hydrogen.
  - d. sodium.
2. **What is the quantity being imaged in MRI?**
  - a. The proton of the oxygen atom
  - b. The nuclear spin vector
  - c. Water molecules
  - d. The electron of the hydrogen atom
3. **Which of the following gives rise to an MRI signal?**
  - a. The nuclear spin vector
  - b. The z component of the spin vector
  - c. The transverse components of the spin vector
  - d. Spin vector transverse components equal to zero
4. **Magnetic resonance images can be defined as displays of differences in the**
  - a. intensity of the image contrast.
  - b. intensity of the MRI signal.
  - c. proton distribution.
  - d. magnetic field intensity of the MRI unit.
5. **In diffusion-weighted MRI, image contrast is generated by variations in**
  - a. the rate of water diffusion.
  - b. blood oxygen levels.
  - c. relaxation times.
  - d. proton density.
6. **Which is NOT true of diffusion-weighted MR images?**
  - a. Magnetic field gradient pulses are applied after nuclear spin excitation but before data acquisition.
  - b. Diffusion-weighted MR images are obtained by adding two magnetic field gradient pulses to generate spatial variations of the main magnetic field.
  - c. Attenuation of the signal's intensity occurs along the axis to which the gradient pulses are applied.
  - d. The greater the signal attenuation, the brighter the diffusion-weighted MR image.
7. **Brain regions of ischemic infarction appear in DW images as \_\_\_\_\_, \_\_\_\_\_ areas.**
  - a. hyperintense; dark
  - b. hyperintense; bright
  - c. hypointense; dark
  - d. hypointense; bright
8. **The occurrence of motion artifacts in DW-MRI can be reduced by using**
  - a. 3.0-Tesla MRI units instead of 1.5-Tesla ones.
  - b. echo planar imaging (EPI), or fast spin-echo imaging (FSEI).

- c. T1- and T2-weighted imaging.  
d. proton density-weighted imaging.
- 9. Besides images, diffusion data can be presented in DW-MRI with maps of**
- the apparent diffusion coefficient (ADC) of water.
  - proton distribution in water molecules.
  - the absolute diffusion coefficient (ADC) of water.
  - the apparent diffusion coefficient (ADC) of hydrogen.
- 10. Which of the following is a TRUE statement about ADC maps?**
- They are generated when it is impossible to obtain diffusion-weighted images.
  - They are calculated from diffusion-weighted images.
  - They are not useful for detecting the core of the ischemia.
  - They are produced instead of diffusion-weighted images.
- 11. Brain regions of ischemic infarction appear in ADC maps as \_\_\_\_\_, \_\_\_\_\_ areas.**
- hypointense; bright
  - hyperintense; bright
  - hyperintense; dark
  - hypointense; dark
- 12. What is the most common type of ischemic stroke?**
- Thrombotic
  - Embolic
  - Apoptic
  - Hemorrhagic
- 13. Neuronal cell death after stroke occurs when the cerebral blood flow falls below**
- 60 mL/100g/min.
  - 30 mL/100g/min.
  - 20 mL/100g/min.
  - 15 mL/100g/min.
- 14. Cytotoxic edema is caused by**
- dysfunction of the cell membrane sodium pump.
  - an increase in body temperature.
  - a reduction in brain tissue water.
  - failure of the cell membrane calcium pump.
- 15. Diffusion-weighted MRI can detect cerebral ischemia within**
- hours.
  - days.
  - minutes.
  - Diffusion-weighted MRI cannot detect cerebral ischemia.
- 16. In one study, diffusion-weighted MRI accurately predicted ischemic stroke in**
- 35% of cases compared to 95% identified with T2-weighted MRI.
  - 92% of cases compared to 33% identified with T2-weighted MRI.
  - 92% of cases compared to 95% identified with T2-weighted MRI.
  - 71% of cases compared to 80% identified with T2-weighted MRI.
- 17. In the same study, MRI had the greatest accuracy when performed within \_\_\_\_\_ hours.**
- 6
  - 8
  - 24
  - 48
- 18. According to the latest research, which of the following statements is TRUE?**
- One of the disadvantages of diffusion-weighted MR images is that only expert technologists can interpret them correctly.
  - Both expert and novice technologists can detect ischemia in diffusion-weighted images.
  - Novice technologists should not attempt to interpret diffusion-weighted images.
  - Diffusion-weighted images can be interpreted only by neurologists.
- 19. Diffusion-weighted MRI can help identify ischemic regions that can potentially be rescued (i.e., the penumbra) if used**
- alone.
  - within one hour of the onset of symptoms.
  - in combination with medications.
  - in combination with perfusion imaging.
- 20. The latest of a series of studies on 1.5-T and 3.0-T diffusion-weighted MRI found that**
- 1.5-T diffusion-weighted imaging allows for the detection of a greater number of ischemic strokes than 3.0-T diffusion-weighted imaging.
  - 3.0-T diffusion-weighted imaging allows for the detection of a greater number of ischemic strokes than 1.5-T diffusion-weighted imaging.
  - 1.5-T diffusion-weighted imaging is as accurate as 3.0-T diffusion-weighted imaging.
  - 3.0-T diffusion-weighted imaging allows for the detection of a greater number of ischemic strokes than 1.5-T diffusion-weighted imaging, but requires more time to perform.



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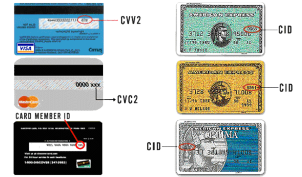
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