Pictorial Essay

Hypointensity on Diffusion-Weighted MRI of the Brain Related to T2 Shortening and Susceptibility Effects

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Because diffusion-weighted images are inherently T2-weighted, changes in tissue T2 can influence the appearance of diffusion-weighted images independent of tissue diffusibility. The effect of prolonged T2—that is, of T2 "shine-through"—is well known. Less well described are the effects of T2 shortening on the appearance of diffusion-weighted images. The goal of this article is to show examples of how T2 shortening influences the appearance of diffusion-weighted images.

Basic Concepts

The signal intensity (*SI*) on a diffusion-weighted image is influenced by T2, the apparent diffusion coefficient (*ADC*), b value (*b*), spin density (*SD*), and TE and is calculated as follows:

$$SI = SI_{b=0}e^{-bADC},$$

where $SI_{b=0}$ is the signal intensity on the spin-echo echoplanar image (T2-weighted image where b = 0). However,

$$SI_{b=0} = kSD(1 - e^{-TR/T1})e^{-TE/T2},$$

where k is a constant.

Moreover, for TR >> T1,

$$SI = kSDe^{-TE/T2}e^{-bADC}$$

From this theory, we may consider the three conditions that may occasionally be confused in the interpretation of diffusion-weighted images.

T2 Shine-Through

This well-known phenomenon causes hyperintensity on diffusion-weighted images as a result of T2 prolongation, such as in subacute to chronic infarction [1]. A decreased apparent diffusion coefficient can be observed, which results in the accentuation of hyperintensity on diffusion-weighted images.

T2 Washout

The term "T2 washout" implies isointensity on diffusion-weighted images due to a balance between hyperintensity on T2-weighted images and an increased apparent diffusion coefficient [2]. T2 washout is often seen in vasogenic edema. To the best of our knowledge, there have been no systematic reports about pathologic conditions that are characterized by isointensity on diffusion-weighted images caused by a balance of hypointensity on T2-weighted images and a decreased apparent diffusion coefficient.

T2 Blackout

The term "T2 blackout" indicates hypointensity on diffusion-weighted images caused by hypointensity on T2-weighted images. T2 blackout is commonly seen in some hematomas [3]. The cause of T2 blackout is predominantly susceptibility effects. However, other conditions show hypointensity on diffusion-weighted images independent of tissue diffusibility, and this pictorial essay illustrates several of these conditions.

Normal Iron Deposition

In the normal adult brain, the globus pallidus, substantia nigra, red nucleus, and dentate nucleus may show hypointensity on T2-weighted images [4] (Fig. 1). This hypointensity may be caused by susceptibility effects that result from physiologic senile iron deposition. On diffusion-weighted images, these areas can also show hypointensity. Apparent diffusion coefficient maps may appear normal, and it might be inaccurate to calculate the apparent diffusion coefficient because of

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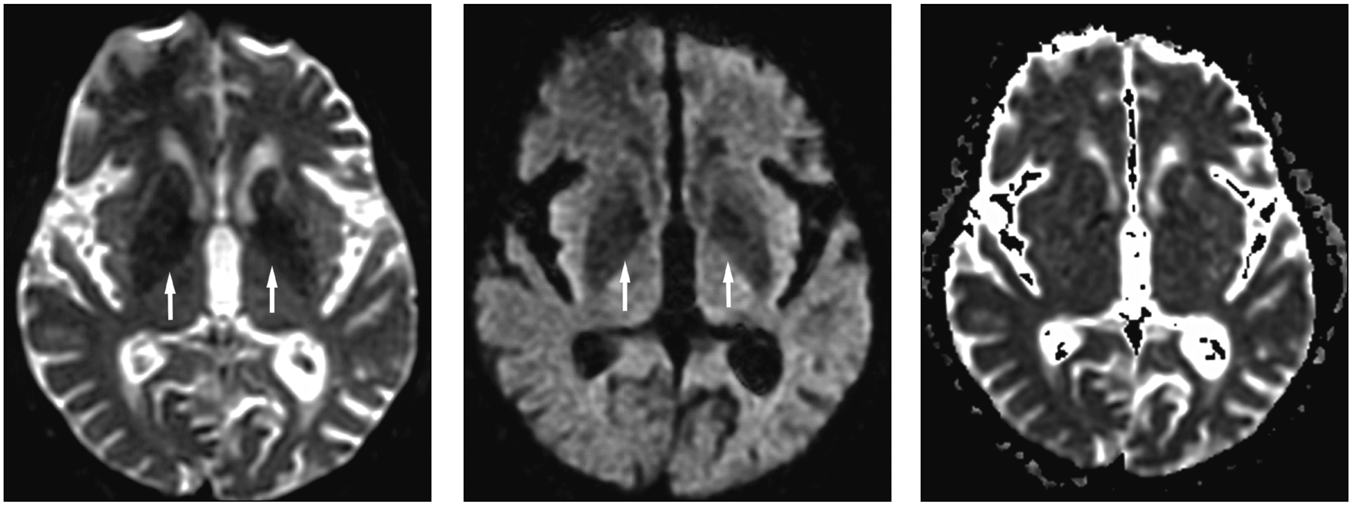
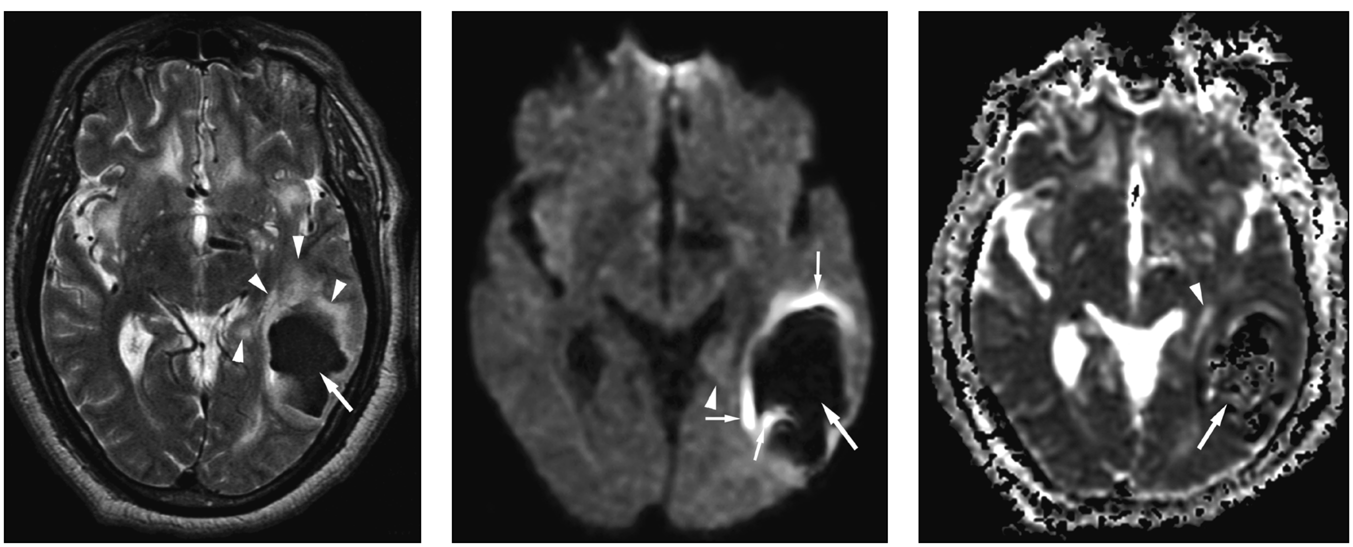


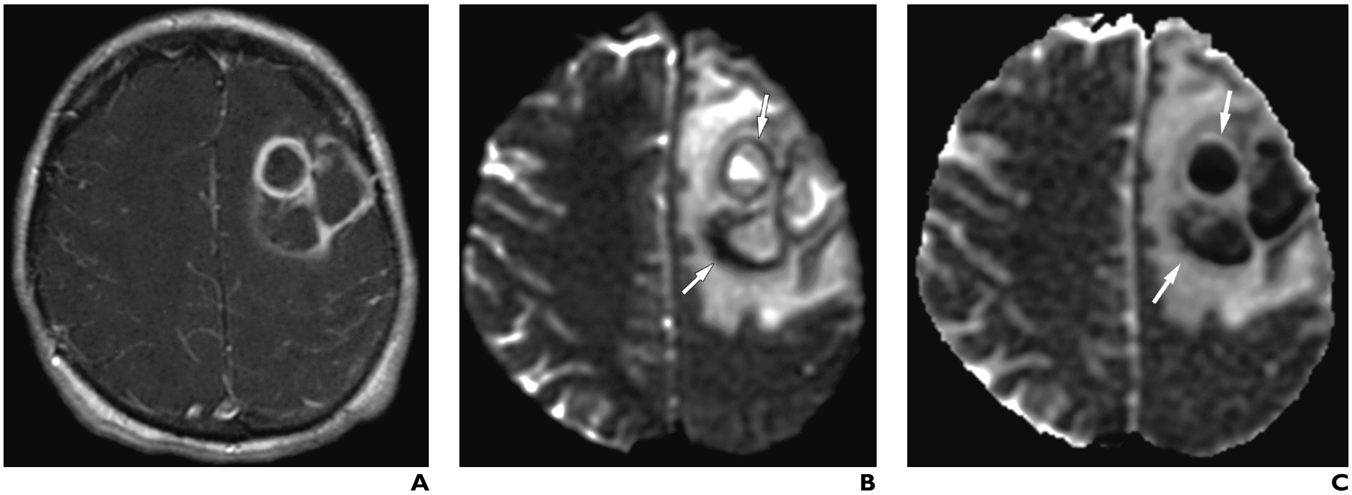
A B C

Fig. 1.—90-year-old man without neurologic deficit.
A, T2-weighted (b = 0) image shows hypointensity in deep gray nuclei (*arrows*) due to senile iron deposition.
B, Diffusion-weighted (b = 1,000) image also shows hypointensity in same distribution (*arrows*).
C, Apparent diffusion coefficient map shows normal appearance of deep nuclei, which proves that hypointensity seen in **B** is effect of hypointensity on T2-weighted image where b is zero rather than increased diffusibility. This example underscores how hypointensity on T2-weighted image can influence appearance of diffusion-weighted image independent of tissue diffusibility.



A B C

Fig. 2.—49-year-old man with acute hemorrhage.
A, T2-weighted fast spin-echo image shows hypointense hemorrhage (*arrow*) in left temporal lobe with areas of surrounding hyperintensity (*arrowheads*), which is consistent with edema.
B, Diffusion-weighted (b = 1,000) image shows hypointensity in central part of hemorrhage (*large arrow*) and hyperintensity in region of edema (*arrowhead*). Additionally, there are curvilinear areas of marked hyperintensity (*small arrows*) that most likely represent regions of focal susceptibility artifact caused by paramagnetic effects of blood products.
C, Apparent diffusion coefficient (ADC) map shows heterogeneous values of ADC within hemorrhage (*arrow*) and thin rim of increased ADC along margin (*arrowhead*), which is consistent with edema. This example shows how hypointensity on T2-weighted image and susceptibility effects can combine to produce complex appearance in and around cerebral hemorrhage.



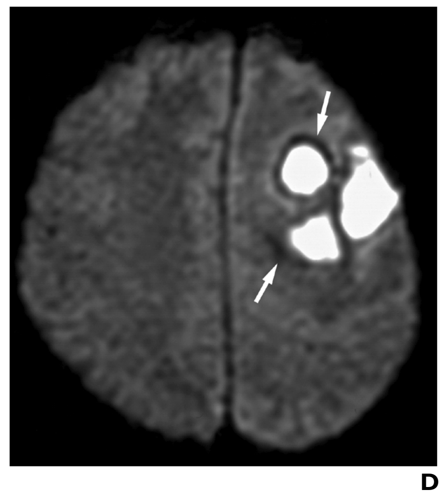


Fig. 3.—38-year-old man with bacterial abscesses.
A, Contrast-enhanced T1-weighted image shows ring-enhancing lesions in left frontal lobe.
B, T2-weighted (b = 0) image shows hyperintensity in cavities, hypointensity in rims (*arrows*), and hyperintensity in surrounding areas.
C, Apparent diffusion coefficient map shows hypointensity in cavities, hyperintensity in rims (*arrows*), and hyperintensity in surrounding areas.
D, Diffusion-weighted (b = 1,000) image shows hyperintensity in cavities, hypointensity in rims (*arrows*), and isointensity in surrounding areas. Hyperintensity in cavities is ascribed to restricted diffusion. Isointensity in surrounding edema is ascribed to balance between hyperintensity on T2-weighted image and increased diffusibility. Hypointensity in rims is ascribed to both hypointensity on T2-weighted image and increased diffusibility. This example also shows how tissue T2 and diffusibility can influence appearance of diffusion-weighted image.

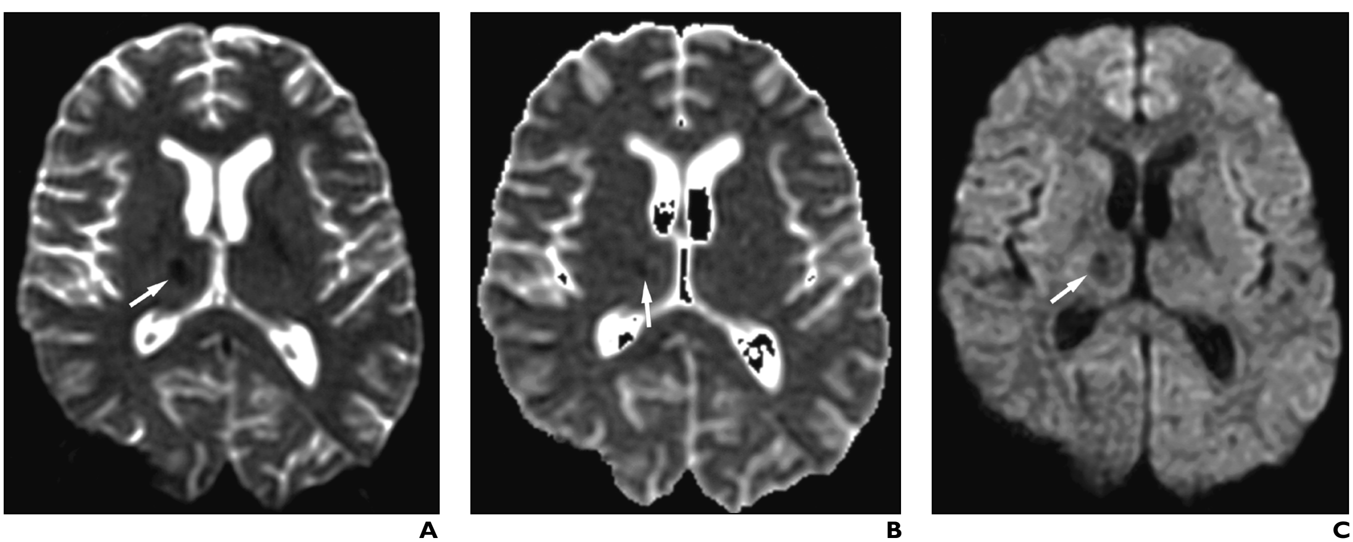


Fig. 4.—28-year-old woman with chronic toxoplasmosis.
A, T2-weighted (b = 0) image shows hypointensity in right thalamus (*arrow*) probably due to granulation tissue.
B, Apparent diffusion coefficient map shows mild hypointensity (*arrow*) in right thalamus.
C, Diffusion-weighted (b = 1,000) image shows hypointensity (*arrow*). This example also shows how hypointensity on T2-weighted image can influence appearance of diffusion-weighted image independent of tissue diffusibility.

the susceptibility effects produced by local field inhomogeneity.

Hemorrhage

In hemorrhage, oxyhemoglobin evolves sequentially: first to deoxyhemoglobin, then to methemoglobin, and finally to hemosiderin or ferritin. Oxyhemoglobin is diamagnetic and has been reported to show hyperintensity on T2- and diffusion-weighted images with a decreased apparent diffusion coefficient. Being paramagnetic, deoxyhemoglobin, intracellular methemoglobin, hemosiderin, and ferritin may cause hypointensity on T2- and diffusion-weighted images (Fig. 2). A decreased apparent diffusion coefficient in hemorrhage with intact RBC membranes and an increased apparent diffusion coefficient after lysis of RBC membranes have been reported [5]. The latter can be related to dilution of methemoglobin in the extracellular fluid. However, measurements of diffusion in areas with susceptibility effects can be problematic because of local field distortions.

Infections

Bacterial Abscess

It is well known that the cavity of bacterial abscess will show hyperintensity on diffusion-weighted images with a decreased apparent diffusion coefficient, probably because of pus formation. Bacterial abscess often has the rim that has been reported to show hypointensity on T2-weighted images, probably ascribed to paramagnetic free radicals released from macrophages and microhemorrhage. The rim also shows hypointensity on diffusion-weighted images and T2-weighted images where b is zero, and this finding might be more prominent on these images than on conventional T2-weighted images. Because this hypointensity is one of the characteristic findings of bacterial abscesses, evaluating diffusion-weighted and T2-weighted images where b is zero in addition to the conventional T2-weighted images is useful (Fig. 3).

Toxoplasmosis

Abscess due to toxoplasmosis has been reported to show homogeneous hypointensity on diffusion-weighted images with an increased apparent diffusion coefficient [6]. However, the signal intensity on diffusion-weighted images may be variable in the acute phase of toxoplasmosis. In the chronic phase, the lesion shows hypointensity on T2-weighted images, probably because of granulomatous changes that also cause hypointensity on diffusion-weighted images and T2-weighted images where b is zero (Fig. 4).

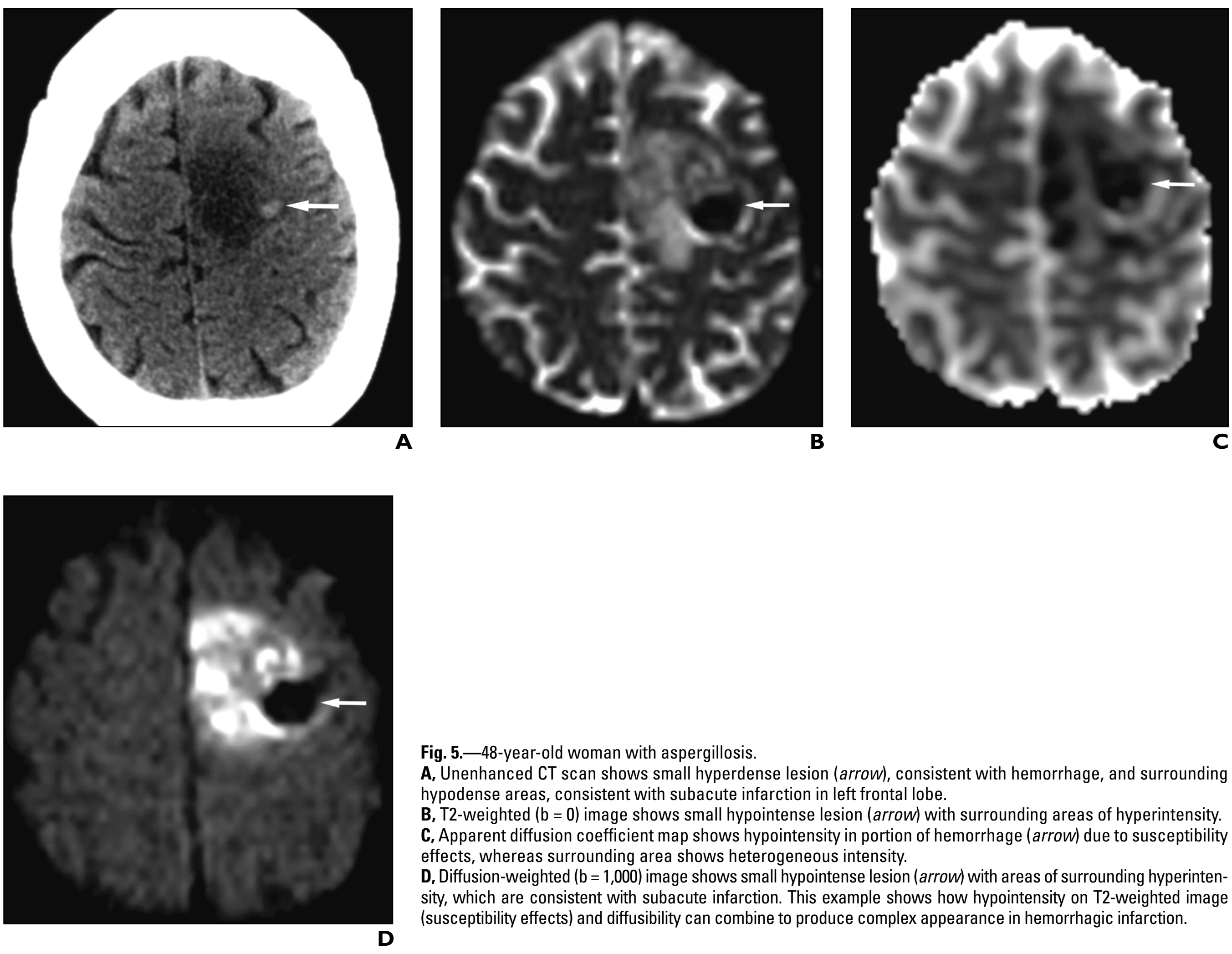


Fig. 5.—48-year-old woman with aspergillosis.
A, Unenhanced CT scan shows small hyperdense lesion (*arrow*), consistent with hemorrhage, and surrounding hypodense areas, consistent with subacute infarction in left frontal lobe.
B, T2-weighted (b = 0) image shows small hypointense lesion (*arrow*) with surrounding areas of hyperintensity.
C, Apparent diffusion coefficient map shows hypointensity in portion of hemorrhage (*arrow*) due to susceptibility effects, whereas surrounding area shows heterogeneous intensity.
D, Diffusion-weighted (b = 1,000) image shows small hypointense lesion (*arrow*) with areas of surrounding hyperintensity, which are consistent with subacute infarction. This example shows how hypointensity on T2-weighted image (susceptibility effects) and diffusibility can combine to produce complex appearance in hemorrhagic infarction.

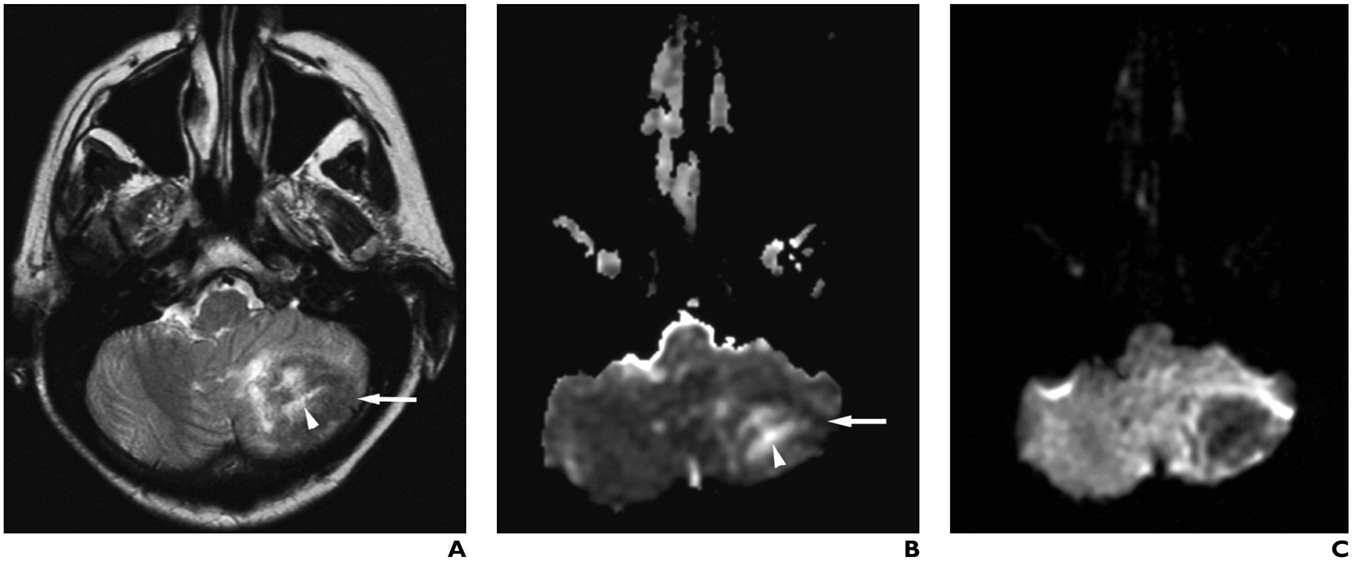


Fig. 6.—61-year-old woman with metastasis from adenocarcinoma of lung.
A, T2-weighted fast spin-echo image shows heterogeneous mass with surrounding hyperintensity, which is consistent with edema in left cerebellar hemisphere. Peripheral portion of this tumor shows hypointensity (*arrow*) that is consistent with noncystic–necrotic component, whereas central portion shows hyperintensity (*arrowhead*) that is consistent with cystic–necrotic component.
B, Apparent diffusion coefficient map shows hypointensity (*arrow*) in peripheral noncystic–necrotic portion and hyperintensity (*arrowhead*) in cystic–necrotic portion.
C, Diffusion-weighted (b = 1,000) image shows hypointensity throughout tumor. Cause of this hypointensity of peripheral noncystic–necrotic portion is related to hypointensity on T2-weighted images, and cause of hyperintensity of central cystic–necrotic portion is related to increased diffusibility. This example also shows how hypointensity on T2-weighted image and increased diffusibility can combine to produce complex appearance in metastatic adenocarcinoma.

Aspergillosis

In disseminated aspergillosis, infiltration to the arteries is seen causing hemorrhagic infarction or cerebritis. The latter may induce abscess formation. On the other hand, granulomatous aspergillosis is more fibrotic than disseminated aspergillosis. This lesion shows hypointensity on T2-weighted images that is probably caused by hemorrhage or iron accumulation [7]. Because hemorrhage and iron deposition are characteristics of aspergillosis, diffusion-weighted images and T2-weighted images where b is zero are helpful for detecting these lesions (Fig. 5).

Metastasis

Most metastatic tumors are hyper- or isointense on T2-weighted images, but some, such as metastatic adenocarcinoma, show hypointensity [8] (Fig. 6). The mechanism is uncertain, but it has been ascribed to the presence of blood, mucin, iron, necrosis, or calcium. Hemorrhagic metastases such as melanoma, lung carcinoma, choriocarcinoma, thyroid carcinoma, and renal cell carcinoma may also show hypointensity on diffusion-weighted images and T2-weighted images where b is zero because of susceptibility effects. These images are useful for detecting the hemorrhage, necrosis, or inflammation in a tumor.

Conclusion

The interpretation of hypointensity on diffusion-weighted images requires correlation with apparent diffusion coefficient maps and T2-weighted images where b is zero to gain an understanding of the underlying pathophysiologic conditions. Hypointensity on diffusion-weighted images due to T2 shortening and susceptibility effects occurs in a variety of conditions such as those in which iron deposition, hemorrhage, and granulomatous tissue are characteristic. Knowledge of these pitfalls will improve our ability to correctly interpret diffusion-weighted images.

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