15 Image Resolution: Pixel and Voxel Size

A pixel represents the smallest sampled 2D element in an image. It has dimensions given along two axes in mm, dictating in-plane spatial resolution. Pixel sizes range in clinical MRI from mm (e.g., 1×1 mm^2) to sub-mm. A voxel is the volume element, defined in 3D space. Its dimensions are given by the pixel, together with the thickness of the slice (the measurement along the third axis). Slice thicknesses in clinical MRI vary from a maximum near 5 mm, achieved using 2D multislice imaging, to sub-mm, achieved with 3D scan techniques.

MRI spatial resolution, which determines the radiologist's ability to distinguish structures as separate and distinct from each other (together with image contrast), is inherently related to the acquired voxel volume. In the simplest case, the field of view (FOV), acquisition matrix, and the slice thickness determine voxel volume. The pixel size (FOV/matrix) determines the in-plane resolution. Reducing the FOV, increasing the matrix number, or reducing the slice thickness results in an image with reduced voxel volume. SNR is directly proportional to voxel size (assuming that the number of phase encoding steps is held constant). Small voxels produce MR images with high spatial resolution but a lower signal-to-noise ratio (SNR), and thus may appear "grainy" compared with images acquired with a larger voxel volume.

The images shown in **Fig. 15.1** demonstrate the effect of altering pixel size. The scans were acquired using T1-weighted technique at 3 T and illustrate a small enhancing lesion (arrow). By appearance alone, the lesion would be consistent with a metastasis, but in this patient it represents a small tumor focus in a multicentric glioblastoma. The pixel dimensions were (a) 0.9×0.9 mm^2 versus (b) 0.5×0.5 mm^2. The slice thickness was held constant. Note the improved anatomic detail in (b)—for example, the "sharpness" with which small enhancing vessels are depicted—due to
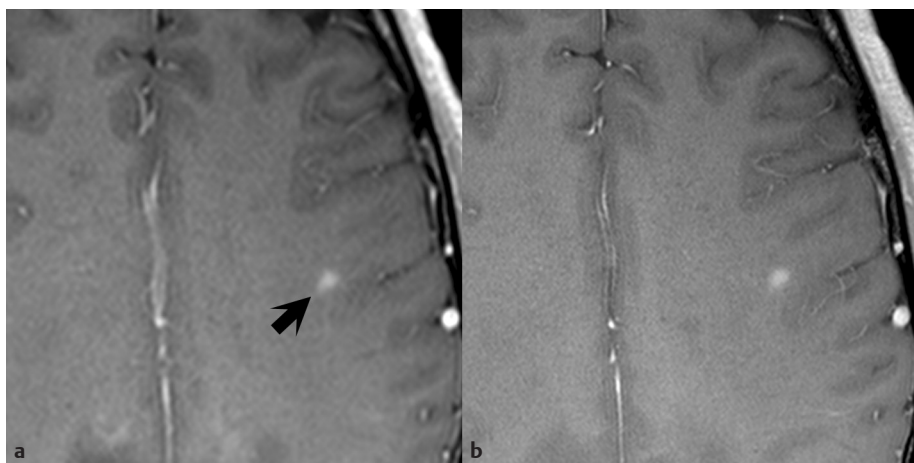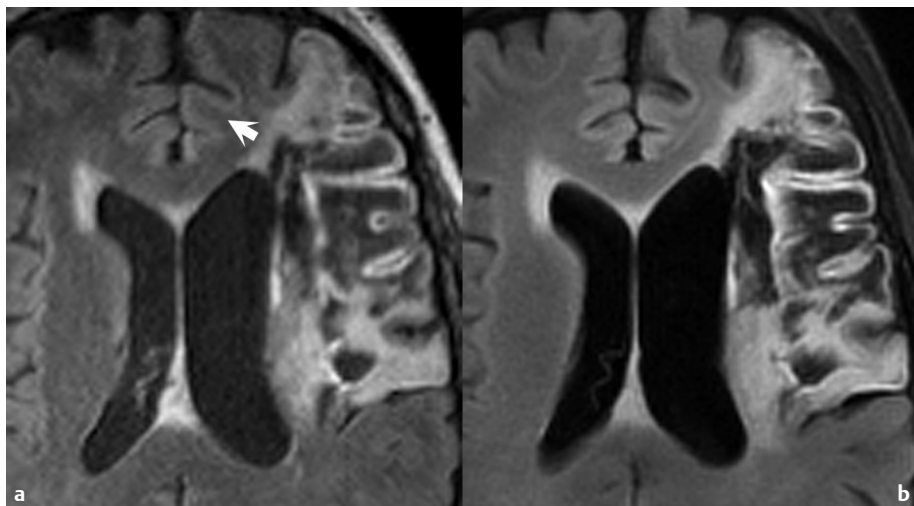

Fig. 15.1

Fig. 15.2

the improved in plane spatial resolution (smaller pixel size). To achieve a high-quality diagnostic image, however, scan time was tripled (three averages as opposed to one). From basic MR physics, the reduction in pixel dimension resulted in a factor of 3 loss in SNR, which was only in part compensated for by the increase in scan averages (SNR being proportional to the square root of the number of scan averages). To summarize, reducing the pixel size increases spatial resolution but also markedly decreases SNR (assuming all other factors are held constant).

The images in **Fig. 15.2** demonstrate the effect of altering slice thickness (and thus voxel size). Illustrated on FLAIR scans is a large, left-sided, chronic middle cerebral artery infarct. Slice thickness was (a) 1 mm versus (b) 4 mm, with equivalent scan time. The 1-mm section appears "grainy," reflecting the low SNR, as compared with the 4-mm section. However, the border between cortical gray and white matter (arrow) is better depicted on the thinner section, despite the poor SNR, due to less partial volume imaging.

Fig. 15.2A was acquired using a 3D scan technique to achieve a 1-mm slice thickness. A 3D acquisition excites an entire slab or volume of tissue rather than a slice. The slices are produced by the application of an additional phase encoding gradient in the slice (z) direction. The number of slices (sometimes referred to as "partitions") desired determines the number of phase encoding steps to be applied in the slice direction and thus directly affects scan time. 3D acquisitions are useful for acquiring thin contiguous slices. In addition, reformatted images from a 3D dataset (e.g., in the sagittal and coronal planes) will be of high quality if the voxel dimensions are near isotropic (equal in all three dimensions). **Fig. 15.2B** was acquired using 2D multislice fast spin echo (FSE) technique, a common approach for screening exams using thicker slices (4 mm in this instance).

SNR in MR can be a very complicated subject. But it is simply the signal divided by the noise in an image (see Chapter 16). Looking only at image resolution and matrix size, the signal is directly proportional to the acquisition voxel volume. The noise is proportional to the inverse of the square root of the number of 2D phase encoding steps times the number of 3D phase encoding steps. Thus, more simply, SNR is directly proportional to voxel volume, if the number of phase encoding steps is held constant.