Diffuse Axonal Injury

Although it is most often affected, the surface of the brain is not the only region damaged by traumatic injuries. Also affected may be the deep white matter regions (the corpus callosum, paraventricular, and hippocampal areas in the supratentorial compartment), cerebral peduncles, brachium conjunctivum, superior colliculi, and deep reticular formation in the brainstem. The microscopic findings include axonal swelling, indicative of *diffuse axonal injury*, and focal hemorrhagic lesions. As many as 50% of individuals who develop coma shortly after trauma, even without cerebral contusions, are believed to have diffuse axonal injury. Axons are injured by the direct action of mechanical forces, with subsequent alterations in axoplasmic flow. Comparable mechanical disruption of axons can result from angular acceleration alone, which can cause diffuse axonal injury even in the absence of impact.

MORPHOLOGY

Diffuse axonal injury is characterized by widespread, often asymmetric axonal swellings that appear within hours of the injury and may persist for much longer. The swelling is best demonstrated with silver impregnation techniques or with immunoperoxidase stains for axonally transported proteins, such as amyloid precursor protein and α-synuclein. Later, increased numbers of microglia areas are seen in damaged areas of the cerebral cortex, and subsequently there is degeneration of the involved fiber tracts.

Traumatic Vascular Injury

Vascular injury is a frequent component of CNS trauma. It results from direct trauma and disruption of the vessel wall, and leads to hemorrhage in different anatomic sites (Table 28-1). Depending on the position of the ruptured vessel, hemorrhage may occur in the *epidural*, *subdural*, *subarachnoid*, and *intraparenchymal* compartments, sometimes in combination (Fig. 28-10). Both epidural and subdural hemorrhages rarely occur outside of the setting of trauma; in some settings such as coagulopathy or significant cerebral atrophy, subdural hemorrhages can follow even minor trauma. A traumatic tear of the carotid artery where it traverses the carotid sinus may lead to the formation of an arteriovenous fistula.

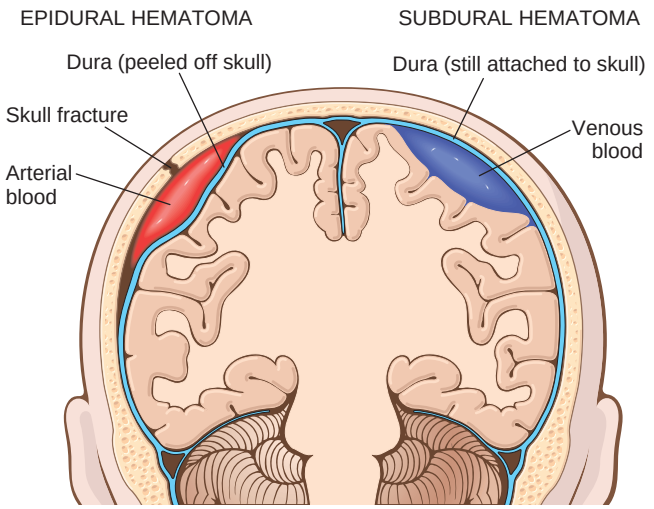

Figure 28-10 Epidural hematoma *(left)* in which rupture of a meningeal artery, usually associated with a skull fracture, leads to accumulation of arterial blood between the dura and the skull. In a subdural hematoma *(right)*, damage to bridging veins between the brain and the superior sagittal sinus leads to the accumulation of blood between the dura and the arachnoid.

Epidural Hematoma

Normally the dura is fused with the periosteum on the internal surface of the skull. Dural arteries, most importantly the middle meningeal artery, are vulnerable to injury, particularly with temporal skull fractures in which the fracture lines cross the course of the vessel. In children, in whom the skull is deformable, a temporary displacement of the skull bones leading to laceration of a vessel can occur in the absence of a skull fracture.

Once a vessel has been torn, the extravasation of blood under arterial pressure can cause the dura to separate from the inner surface of the skull (Fig. 28-11). The expanding hematoma has a smooth inner contour that compresses the brain surface. When blood accumulates slowly patients may be lucid for several hours before the onset of neurologic signs. An epidural hematoma may expand rapidly and is a neurosurgical emergency requiring prompt drainage.

Table 28-1 Patterns of Vascular Injury in the Central Nervous System

Location	Etiology	Additional Features
Epidural space	Trauma	Usually associated with a skull fracture (in adults); rapidly evolving neurologic symptoms, requiring intervention
Subdural space	Trauma	Level of trauma may be mild; slowly evolving neurologic symptoms, often with a delay from the time of injury
Subarachnoid space	Vascular abnormalities (Arteriovenous malformation or aneurysm)	Sudden onset of severe headache, often with rapid neurologic deterioration; secondary injury may emerge, associated with vasospasm
	Trauma	Typically associated with underlying contusions
Intraparenchymal	Trauma (contusions)	Selective involvement of the crests of gyri, where the brain may contact the inner surface of the skull (frontal and temporal tips, orbitofrontal surface)
	Hemorrhagic conversion of an ischemic infarction	Usually petechial hemorrhages in an area of previously ischemic brain, usually following the cortical ribbon
	Cerebral amyloid angiopathy	"Lobar" hemorrhage, involving cerebral cortex, often with extension into the subarachnoid space
	Hypertension	Centered in the deep white matter, thalamus, basal ganglia, or brainstem; may extend into the ventricular system
	Tumors (primary or metastatic)	Associated with high grade gliomas or certain metastases (melanoma, choriocarcinoma, renal cell carcinoma)