Until a few years ago, conventional X-rays were the imaging standard for cranio-cerebral and facial trauma. Today, however, computed tomography (CT) has become the primary imaging method, along with significant technical improvements, especially with the development of multislice CT.

Conventional X-rays are relatively sensitive to cranial vault fractures, but insensitive to fractures of the skull base and facial skeleton. CT enables a precise diagnosis of all kind of fractures of the facial skeleton and skull base, and additionally delivers information about intracranial bleeding and injuries to the cerebrum. In the multi-traumatized patient, CT can be extended to the cervical spine as well as the trunk if necessary. A complete body check for traumatic lesions can be done within a few minutes, including the brain, spine, bone, and organs. Thus, conventional X-rays of the skull are no longer used in the case of head trauma or polytraumatized patients; CT is widely accepted as the primary imaging method of choice. Nevertheless, the following provides an overview of all imaging methods, including conventional X-rays.

2.1 Conventional X-Rays

The standard X-ray exposures for the skull are summarized in Table 2.1. Standard projections are the anterior/posterior (AP) and the lateral view of the whole skull. These images are sensitive to skull fractures, which fall under two general categories: (1) direct fractures identifiable as fracture lines, fracture gaps and dislocation of osseous fragments of the skull; (2) indirect fractures identified as opacification of the paranasal sinuses and soft tissue emphysema. For the facial skeleton, the semi-axial view of the midface is required either in occipito-mental or occipito-frontal projections, while fractures of the mandible require the panoramic and the Clementschitsch view.

The sensitivity of the different exposures for fractures varies depending on fracture type. Some simple fractures can be well displayed on dedicated X-ray projections. On the other hand, complex fractures can only be partially evaluated because of the overlap of the various structures in the craniofacial skeleton, the complexity of which demands considerable expertise in evaluation (Figs. 2.1–2.6).

2.2 Computed Tomography

CT is an X-ray imaging method where the X-ray source rotates around the patient, giving information about the density of the tissues (attenuation profiles) in the slice within the X-ray beam. The attenuation profiles of the slice are Fourier transformed into a matrix of digital values representing a digital image of the slice. Every pixel of the image represents a small volume element (voxel) in the patient. There is density averaging within the voxels (partial volume effects), but no superimposition of structures. The thinner the slice, the lesser are partial volume effects and density averaging. CT permits the analysis of the anatomical structures within the patient without superimposition of structures, and with a relatively good tissue density characterization, which can even be improved by the injection of intravenous contrast material (CM).
Table 2.1 Conventional X-ray techniques for the skull

<table>
<thead>
<tr>
<th>X-ray</th>
<th>Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull X-ray in two planes</td>
<td>Cranial fractures</td>
</tr>
<tr>
<td>Skull occipito-frontal and occipito-mental</td>
<td>Fractures of the facial skeleton</td>
</tr>
<tr>
<td>Occipital exposure (Towne view)</td>
<td>Fractures of the occipital bone</td>
</tr>
<tr>
<td>Mandible (Clementsichts view)</td>
<td>Fractures of the mandible</td>
</tr>
<tr>
<td>Mandible unilateral in oblique position</td>
<td>Fractures of the horizontal branch of the mandible</td>
</tr>
<tr>
<td>Panoramic X-ray</td>
<td>Tilted collum or fracture of the mandibular condyle</td>
</tr>
<tr>
<td>Pan-handle X-ray (axial X-ray of the skull)</td>
<td>Collum-condyle-fractures, mandibular fractures, dento-alveolar traumas</td>
</tr>
<tr>
<td>Unilateral exposure of zygomatic bone</td>
<td>Fractures of the zygomatic arch</td>
</tr>
<tr>
<td>Lateral view of nasal bone</td>
<td>Fracture of the nasal bone</td>
</tr>
</tbody>
</table>

Fig. 2.1 Skull fracture on standard X-ray radiographs. Sharp lucent line without sclerotic margins in left frontal bone, distant to sutures and vascular channels (arrow)

Fig. 2.2 Blow-out fracture of the orbital floor. (a) Indirect fracture sign: total opacification of the right maxillary sinus (asterisks). (b) Coronal CT reformatting: depression fracture of the central part of the orbital floor with hematosinus (arrow)
Fig. 2.3  Panoramic X-ray: triple fracture of the mandible. Subcapital collium fracture on the right with dislocation of the capitulum (luxation and massive angulation) (arrow) and left neck base fracture without dislocation (arrow). Right paramedian corpus fracture (arrow).

Fig. 2.4  Clementschitsch view of the mandible: left panel normal X-ray appearance; right panel same patient as in Fig. 2.3. The medial angulation of the right capitulum is well seen in this view (arrow). The corpus fracture is superimposed by mediastinal structures and is not seen in this view.

Fig. 2.5  Fracture of the nasal bone with moderate displacement (arrow).

Fig. 2.6  X-ray view of both zygomatic arches. Fracture of the left zygomatic arch (arrow).
To cover larger parts of the body, multiple adjacent volumes are acquired. Scanning is done by continuous movement of the patient through the CT gantry in combination with continuous rotation of the X-ray tube, resulting in spiral scanning. This technique is called multislice spiral CT (MSCT). The resulting slices are put together to form a stack, which in turn can be analyzed image by image or by reformatting for interactive analysis in arbitrary imaging planes.

MSCT scanners cover up to 40 mm of patient volume in one rotation, split into up to 128 slices, with slices as thin as 0.5 mm or less. Using MSCT, large body segments can be scanned within a few seconds with a submillimeter resolution in all three dimensions. The scanners become more powerful from year to year, with an increase in the number of simultaneously acquired slices and in the volume per rotation.

The primary imaging plane of CT images is axial, but many structures are more easily analyzed in other imaging planes. For the evaluation of the facial skeleton, axial and coronal images are mandatory. Until a few years ago, before the MSCT era, the facial skeleton had to be scanned twice, in the axial and coronal direction separately, resulting in a double dose of radiation. In MSCT,

![Fig. 2.7 Comparison of direct paracoronal scanning of the midface (a, b) to coronal reformations from thin-slice spiral CT datasets (c, d). Direct paracoronal scanning has been abandoned with introduction of multislice spiral CT scanners. In direct paracoronal scanning, patient positioning is uncomfortable because reclination of the head is required. Furthermore, the CT gantry has to be tilted leaving less space for the patient (a). In the images, tooth artifacts superimpose relevant structures (b). Axial thin-section CT scanning allows comfortable patient positioning and scanning without gantry tilt (c). Artifacts remain in the plane of the teeth and do not go across relevant structures (d). There is no image quality loss between reformatted images and original paracoronal images (b, d)
only a single dataset in the axial plane is required. The coronal images and any other planes are reconstructed from the axial images by multiplanar reformatting (MPR) on a computer workstation. A workstation can be a CT workstation or a picture archiving and communication system (PACS) workstation. PACS is the electronic image database system with which most hospitals are equipped today. The image quality of the reconstructed coronal images is similar to that of directly acquired coronal images. MPR analysis is routinely used to detect or exclude fractures of the skull base, optic canal, orbital floor, maxilla, palate, and mandible, as well as to measure the extent of dislocations (Fig. 2.7).

In addition to MPR, three-dimensional views of the scanned object can be calculated using shaded surface display (SSD) or volume rendering (VR) algorithms. VR images are color coded and give an impressive view of the anatomy. The three-dimensional (3D) perspectives are valuable for the analysis and visualization of complex fractures. They give an overview of the main fragments and relevant dislocations, from which conclusions about the trauma mechanism can be drawn. On modern computer workstations, 3D views can be calculated within a few seconds, making 3D visualization a practicable routine diagnostic add-on.

In the case of foreign body penetration injuries, CT sensitivity is variable. Whereas glass and metal are seen very well and detected without prior knowledge of their presence, wood and plastic are difficult to detect and special attention must be given for their possible presence. Wood appears like air and plastic materials have different density.

Intraoperatively, CT datasets can be used for navigation. For this purpose, the primary axial CT images are loaded into a computer program which displays the CT findings at the site or during surgery (Hassfeld et al. 1998; Gellrich et al. 1999, 2003). The images have to be loaded in DICOM format from a CD, DVD, or online from the PACS archive, which is the standard format used in medicine (DICOM, digital image communication in medicine). Postoperatively, CT can be used to check and document the repositioned fracture fragments and the position of the osteosynthesis material.

### 2.4 Ultrasonography

Ultrasonography is not applicable for adult patients with trauma to the head and face, but may be the method of choice for evaluation in children. Sonographic imaging of the brain in young children is possible through the fontanels, which are still open. Also, the high spatial resolution of ultrasound allows skull fractures to be detected. As for the facial skeleton, CT is a necessity for treatment decision, thus rendering ultrasound imaging a waste of time (Fig. 2.9).
2.5 Diagnostic Algorithm

2.5.1 General Considerations

Conventional X-ray is no longer the standard in radiological imaging for cranio-facial trauma detection; this is now carried out by CT imaging. CT is widely available and allows fast scanning of the patient. Soft and hard tissue damage is reliably demonstrated and a first fast overview of the images can be done to identify relevant lesions requiring immediate surgery, such as intracranial hemorrhage or splenic rupture. The CT datasets can then be analyzed thoroughly in an offline situation at the computer workstation, while the patient is brought to the operating room or otherwise managed by the trauma team. MRI is not the primary imaging modality after trauma, although it is sensitive
for the detection of shearing injuries to the brain, albeit this question is raised later after trauma. Shearing injuries are of little significance in the primary posttraumatic situation (Yokata et al. 1991).

The first important issue to be resolved after craniofacial trauma is to exclude space-occupying intracranial hemorrhage or increased intracranial pressure (ICP) requiring neurosurgical intervention. This includes evacuation of hematoma, craniectomy, or ICP monitoring. The second point is to assess bone injury (Schneider and Tölly 1984; Bull et al. 1989; Lehmann et al. 2001; Bowley 2003), identifying and classifying fractures.

Technically, the primary CT after trauma is done as noncontrast-enhanced (NECT) scanning. Intravenous contrast administration is contraindicated since it can obscure small intraparenchymal hemorrhages. Contrast-enhanced CT is added only if, based on the NECT scan, an intracranial tumor is suspected or if significant subarachnoid hemorrhage is detected and a cerebral artery aneurysm must be excluded. CM is injected, however, for CT of the cervical spine and trunk; first NECT scanning of the head, followed by scanning other parts of the body. The usual trauma algorithms for CT respect this issue.

The initial CT scan is usually focused on the neurocranium and usually covers the region from the foramen magnum to the apex of the skull. The maxilla is not completely included, and the mandible is usually excluded. However, if significant trauma to the facial skeleton is suspected, the CT technician should be advised to scan the head completely from the chin to the apex. This is not a problem with modern CT systems.

Fractures of the cervical spine must be excluded in any major cranio-facial trauma. The cervical spine can be scanned immediately after the NECT scan of the head without repositioning the patient. It is, however, advisable to apply i.v. CM to exclude dissection of a vertebral artery. In polytraumatized patients, CT is extended to the thorax and the abdomen, also carried out with i.v. CM injection.

2.5.2 Craniocerebral Trauma

2.5.2.1 The Initial CT After Trauma

The primary structure of observation in the initial head CT is the brain. Is there parenchymal bleeding? Are there signs of diffused brain damage? Are there signs of elevated ICP? Elevated ICP is indicated by narrowing or absence of the external and internal CSF spaces. Narrow spaces may be physiological in young patients. However, absent spaces are never normal, especially if the basal cisterns are not visible. Diffuse brain damage must be suspected if the basal ganglia and cortical structures have the same density as the white matter. This is referred to as “absence of the normal medullo-cortical differentiation”.

Cerebral hemorrhage usually occurs at the polar areas of the brain and at the brain surface. Typical locations are the frontal and temporal poles, the lateral contours of the temporal lobes, and the basal surfaces of the frontal and temporal lobes. In these regions, the brain collides with the bone or glides over the rough skull base or over the edge of the temporal bone during deceleration.

Hemorrhagic contusions are usually small in the initial CT, but nonetheless always indicate significant brain injury and bear the risk of delayed bleeding, the so-called “blooming-up” of contusional hemorrhages. As a further complication, brain swelling can develop. In order not to miss these complications, CT should be repeated 6–24 h after trauma. The risk of continuing hemorrhage and significant hematomas is high in patients on anticoagulant drugs. In these patients, the CT should be repeated earlier, usually after 4–6 h. The need for ICP monitoring by a surgically placed probe depends on the initial CT findings and is managed by the neurosurgeon. Brain swelling may require immediate or delayed decompression by craniectomy. Also, large hematomas or massive cerebellar swelling in the posterior fossa can result in obstruction of the fourth ventricle and cause hydrocephalus, and may require ventricular drainage (Fig. 2.10).

The second thing to look for is extracerebral hemorrhage. There may be epidural or subdural hematomas (SDHs). Large hematomas with a significant mass effect require immediate surgery. Subarachnoid hemorrhages (SAH) may be present, but almost never require intervention since they generally resolve spontaneously. Still, one should be aware that a SAH may be caused by a ruptured cerebral artery aneurysm, and the rupture of the aneurysm can be the cause for the trauma. If there is significant spread of the SAH in the typical regions around the basal arteries in the basal cisterns, a contrast-enhanced arterial phase CT should be added to look for cerebral aneurysms. If there is no aneurysm on CT, cerebral angiography should be discussed. In the long term,
SAH may cause CSF malresorption and hydrocephalus weeks to months after trauma and require ventricular drainage. Multiple or combined hemorrhages in different areas indicate semi-severe to severe cranio-cerebral trauma. The need for a “second look” CT scan after 12–24 h has already been mentioned. The need for further follow-up CTs will depend on the patient’s clinical course (Figs. 2.11–2.15).

The third thing to look for is fractures. Singular undisplaced skull fractures are of little clinical

Fig. 2.10 Signs of brain swelling after severe trauma. Compression of the external CSF spaces especially in the tentorial area. Little subarachnoid hemorrhage in the insular cistern on the left side

Fig. 2.11 Intracerebral hemorrhage (ICH) and midface fracture (left orbital floor): which was first? In this case, the ICH was first and led to collapse of the patient with midface fracture. Location and size of the hemorrhage represent a typical hypertensive bleeding (arrow) and not a superficial contusion injury
significance unless they cause epidural hematomas (EDH). Depressed and displaced fractures with gaps and steps between fragments may require surgery.

In describing a fracture, the first step is to define the affected bone structures:

- Calvarial bones (frontal, temporal, parietal, occipital)
- Anterior and/or posterior wall of the frontal sinus
- Ethmoid (roof, lateral wall)
- Sphenoid sinus, sphenoid wing, optic canal and clivus
Fig. 2.14 Complex bilateral midface fracture and cranio-frontal fracture with little displacement (arrow), but massive brain injury. Frontobasal and right temporo-polar contusion hemorrhages (arrow). Intraventricular hemorrhage with hydrocephalus (arrow). CSF circulation is blocked by the clot in the fourth ventricle leading to slight widening of the temporal horns of the ventricles.

Fig. 2.15 Typical hemorrhagic contusions in both frontal lobes (arrow) after midface trauma. Fracture of the left zygomatic arch and lateral zygomatico-maxillary complex.

- Orbit (roof, medial wall, lateral pillar, orbital floor, optic canal)
- Nasal bone
- Zygoma and zygomatic arch
- Maxillary sinus (anterior and lateral walls, orbital floor)
- Maxilla (alveolar process, teeth, pterygoid process) and palate
2.5 Diagnostic Algorithm

The second step is to define dislocations: impressions, overlaps, and malalignments of the relevant structures. In the CT analysis, one should check the following (Table 2.2, Fig. 2.16):

- Mandible
- Temporal bone and mastoid

In the CT analysis, one should check the following (Table 2.2, Fig. 2.16):

- Skull contours
- Nasion
- Supraorbital margin
- Infraorbital margin
- Lateral orbital wall
- Zygoma
- Zygomatic arch
- Anterior nasal spine

### 2.5.3 Skull Base Fractures

There is a high coincidence of midface fractures and skull base fractures. The skull base is mostly affected in the frontobasal and fronto-ethmoidal regions.

- The high coincidence of facial skeletal fractures and frontobasal and fronto-ethmoidal injuries in midfacial traumas requires a CT scan to evaluate the skull base (Joss et al. 2001; Bowley 2003).

Fracture of the skull base can be the direct extension of skull fractures or orbital fractures into the skull base. For example, a temporal bone fracture can extend into the temporal skull base; a frontal bone fracture can radiate into the orbital roof, ethmoid and sphenoid; or

<table>
<thead>
<tr>
<th>Table 2.2 Radiological findings in trauma CT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Epidural hematoma</strong></td>
</tr>
<tr>
<td>Lens shaped between dura and tabula interna</td>
</tr>
<tr>
<td>Usually stops at skull sutures</td>
</tr>
<tr>
<td>Requires surgery dependent on size</td>
</tr>
<tr>
<td><strong>Subdural hematoma</strong></td>
</tr>
<tr>
<td>Crescent-shaped</td>
</tr>
<tr>
<td>Along the cranial vault</td>
</tr>
<tr>
<td>Along the falx</td>
</tr>
<tr>
<td>Along the tentorium</td>
</tr>
<tr>
<td>Exceeds the skull sutures</td>
</tr>
<tr>
<td>Requires surgery dependent on size</td>
</tr>
<tr>
<td><strong>Traumatic SAH</strong></td>
</tr>
<tr>
<td>Blood in the external CSF spaces (sulci or basal cisterns)</td>
</tr>
<tr>
<td>Traumatic SAH is common in severe cranio-cerebral injuries</td>
</tr>
<tr>
<td>Clinical significance is low</td>
</tr>
<tr>
<td><strong>Nontraumatic SAH</strong></td>
</tr>
<tr>
<td>In each SAH: should think about the possibility of a ruptured cerebral artery aneurysm. A rupture may be the cause for the trauma. Check the trauma history</td>
</tr>
<tr>
<td>If there is a suspicion of an aneurysm, perform an Angio-CT and discuss cerebral angiography</td>
</tr>
<tr>
<td><strong>Parenchymal hemorrhage (contusional hemorrhage)</strong></td>
</tr>
<tr>
<td>Common in mid-severe and severe cerebral trauma</td>
</tr>
<tr>
<td>At surface and on the poles of the brain</td>
</tr>
<tr>
<td>May “bloom up”</td>
</tr>
<tr>
<td>Require additional CT scan (within next 24 h)</td>
</tr>
<tr>
<td>May be accompanied by brain swelling and require decompression surgery</td>
</tr>
<tr>
<td><strong>Signs of space occupying hemorrhage</strong></td>
</tr>
<tr>
<td>Compressed external CSF spaces on the side of the hemorrhage</td>
</tr>
<tr>
<td>Compressed lateral ventricle on the hemorrhage side</td>
</tr>
<tr>
<td>Displacement of the midline to the contralateral side</td>
</tr>
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Compressed tentorial and basal cisterns
Compressed fourth ventricle (if hemorrhage is in the posterior fossa)
Hydrocephalus (when the fourth ventricle is compressed)

**Brain swelling**
Compressed external CSF spaces over the swollen brain parenchymal area
Narrow ipsilateral ventricle
Mid-line displacement
Asymmetry of the tentorial cisterns
**Signs of increased ICP**
Compression of external CSF spaces
Narrowed ventricles
Compression of the tentorial and basal cisterns: Ambiens cistern (lateral to the midbrain) and quadrigeminal cistern (dorsal to the quadrigeminal lamina)
Foramen magnum filled out with brain parenchyma (cerebellar tonsils)

**Intracranial air (pneumocele, pneumatocephalus)**
Open brain injury
Indicates dural laceration
Indicates fracture of temporal bone at the skull base
Look for:
- Frontal skull base fracture
- Sphenoid sinus fracture
- Mastoid fracture
- Temporal bone fracture

**Foreign bodies**
Following penetration injuries
Glass: Most often superficial in skin
Wood: Difficult to detect, because of appearance like air/emphysema
Metal: May cause artifacts
Craniocerebral trauma

an occipital fracture can radiate down into the foramen magnum. Anterior head trauma can result in complex fractures of the frontal skull base and ethmoid bone and may extend into the roof of the sphenoid sinus, the clivus and the sella. Temporal bone fractures can radiate into the petrous bone and mastoid process and cause hemorrhage in the mastoid cells and tympanon. Clinical symptoms are otic hemorrhage, otic liquor-rhea and hearing loss.

Another mechanism leading to skull base fractures is the indirect energy transmission from the mid-face to the skull base through the main vertical pillars. This

Fig. 2.16 Radiological – diagnostic procedure in craniocerebral trauma – flow chart
mainly affects the temporal skull base and the ethmoid. Not associated with mid-face fractures are skull base fractures after axial head trauma from the vertex with fractures in the region of the foramen magnum and the risk of a burst fracture of the first cervical vertebra (atlas ring burst fracture).

There are direct and indirect signs of skull base fractures. Direct signs are fracture lines, fracture gaps and steps between fragments. Indirect signs are intracranial air collections and liquorrhea. Intracranial air collections can be demonstrated in 25–30% of skull base fractures (Probst and Tomaschett 1990). Small air collections are regularly seen with fractures of the temporal bone and sphenoid sinus. Vast air collections (pneumocephalus) occur after destructive fractures of the frontal sinus and ethmoid roof. In the CT dataset, the primary axial images can be demonstrated in 25–30% of skull base fractures (Probst and Tomaschett 1990). Small air collections are regularly seen with fractures of the temporal bone and sphenoid sinus. Vast air collections (pneumocephalus) occur after destructive fractures of the frontal sinus and ethmoid roof. In the CT dataset, the primary axial images can be demonstrated in 25–30% of skull base fractures (Probst and Tomaschett 1990). 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2.5.4 Midface Fractures

For midface fractures, CT images in the axial and coronal planes are obligatory to differentiate fracture types and to define the extent of the fracture. The sagittal plane may be helpful to assess dislocations in the anterior-posterior direction (nasion, maxilla). Oblique sagittal images parallel to the optic nerve or parallel to the inferior rectus muscle of the orbit may be helpful to visualize muscle entrapment in fractures of the orbital floor. The required series of images should be generated by the CT technician. In addition, analysis can be done interactively in a PACS viewer, if available.

CT permits a differentiated fracture assessment and provides evidence of injury in anatomically difficult areas, e.g., the orbits, the naso-orbito-ethmoidal complex, the peri- and retroorbital skull base and the retro-maxillary region (Terrier et al. 1984; Schwener and Peifer 1987; Schneider and Tölli 1984; Manson et al. 1990; Whitaker et al. 1998; Rother 2000).

Classification of midface fractures, according to the classification systems outlined in Chap. 3, surgical planning and intraoperative navigation are based on CT.
Midface fractures

Axial images should be scrutinized for:
- Fractures of the anterior and posterior walls of the frontal sinus
- Fracture of the lateral orbital wall
- Fracture of the medial orbital wall (blow-out fracture)
- Ocular lens luxation or rupture of the ocular bulb
- Fracture and dislocation of the nasal bone
- Fractures of the maxillary sinus with hematosinus
- Hematosinus without apparent wall fracture may indicate fracture of the orbital floor
- Fractures of the anterior lateral walls of the maxillary sinus are associated with inward rotational dislocation of the zygoma
- Fracture of the zygomatic arch
- Fracture of the alveolar crest of the maxilla and of the palate bone
- Mandibular fractures (ramus)

Particular to detection in the coronal images are:
- Fractures of the orbital floor
- Fractures of the orbital and ethmoid roofs (frontal skull base)

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