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# The Traumatic Brain Injury and its Forensic Significance

Following on from the first two parts in this series of articles (see also Brodbeck et al. 2017; Brodbeck et al. 2018; Brodbeck 2020; Brodbeck 2021), which dealt with the grasp reflex and the appearance of bloodstains following head injuries, this third part views at the forensic significance of traumatic brain injuries (TBI) and, in particular, brain edema.[1] Brain edema can be caused by many different influences, such as tumor, trauma or inflammations. Forensically relevant brain edema can also be caused by toxics, e.g. MDMA-induced hyperthermia. Brain edema is of high relevance in the crime scene work of murder cases due to the fact that it may cause delayed impairment in victims after head injuries. This leads to a crime scene where some part of the evidence may be caused by the victim itself and afterwards, although the victim is found dead at the scene. Thus TBI can have an enormous effect upon crime scene reconstruction. Another part of this article describes the effects of TBI upon the memory of victims. Survived TBI can lead to seemingly contradictory statements between perpetrator and victims on the face of it, whereas in reality both statements are very close, taking the TBI into consideration. In this article, we describe this effect as the Broken Continuity Effect (BCE). It should be noted that the term TBI is expressed differently in other languages. Whereas in the English world this injury is described as traumatic brain injury, in the German speaking world it is named "Schädel-Hirn-Trauma" (SHT), which also takes the skull into consideration as an anatomical part of this body area.

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## THE PROBLEM OF ASSESSING BRAIN EDEMA THROUGH AUTOPSY

It is important to understand that brain edema can only be assessed in a very limited way through autopsy. Neither autopsy nor postmortal imaging are able to produce a quantitative view of the brain edema, as regular imaging methods (CAT-Scan or MRI) in the living can show.

One problem of the autopsy is that evolution has resulted in the brain and spinal cord being protected by bone. This is essential for survival systems. In the case of the brain, this is the skull. The viewing of the brain through autopsy requires severe destruction of the surrounding anatomical structures.

Postmortal imaging (see also Brodbeck, 2005; Brodbeck 2008; Berger 2015) also has its limitations. During the dying process, physiological cell death occurs due to hypoxia, therefore brain edema is a natural part of this process. It is not possible to differentiate radiologically between a brain edema caused by other rea-

sons or between the hypoxic brain edema of the dying process, afterwards. In autopsy only larger areas of brain edema may be recognised with the naked eye. In the imaging methods used in the living person, small areas of edema may also be seen and located. There have been several attempts to quantify brain edema in the forensic procedures (Madro/Chagowski 1987), but this has not proved possible. Another critical point in the autopsy is that some traumatic injuries are not apparent to the eye. Injuries at the cellular level are often caused by rotational movement and may cause diffuse damage to the axons, a tearing of the nerve cells. Diffuse axonal injuries (DAI) are therefore a pathological-histological diagnosis and may be missed in a regular autopsy. The same problems of access can be seen in the spinal cord and the spinal column. Often this area is not autopsied due to the high effort involved.

## CLINICAL COURSE OF BRAIN TRAUMA FROM A NEUROSURGICAL VIEW

Before we are able to view the influences of brain trauma on the crime scene and investigation, we have to consider the clinical course of TBI.

Traumatic brain injury is defined through its clinical degree of severity (see also Greenberg 2016; Maas 2017). Graduation systems with three or four steps are used. In the beginning the clinical situation is assessed through the consciousness of the patient via the Glasgow Coma Scale (GCS). It is important to note that the classification of head trauma is a clinical classification.

In the medical classification with three parts, a slight head trauma, e.g. a concussion, does not show pathological finding in the brain imaging (CAT-Scan or MRI). However, it is often accompanied by short periods of unconsciousness and often associated with retrograde amnesia. This means that the person has lost the memory of the traumatic incident. An example of that would be a car accident, where the driver only remembers a place shortly before the accident and later regains the memory upon admission to hospital.

If additional findings in the imaging methods can be seen, such as a bleeding into the brain tissue, the neurosurgical diagnosis is a brain contusion. Clinically it may present the same symptoms as the concussion, often with a longer period of unconsciousness and symptoms consistent with the location of the tissue injury. Moderate and severe TBI differ in clinical situation, duration of the loss of conciousness and retrograde amnesia.

Brain tissue is a very sensitive tissue and nature has protected it by encasing it in cerebro-spinal fluid (CSF), also named liquor cerebrospinalis. Traumatic influences often cause a swelling of the brain called brain edema, of which different variants are known. It can be caused by a range of factors, such as tumors, bleedings and strokes. Brain edema is differentiated by its physiological cause (Greenberg, 2016).

Forensically relevant is that the swelling does not have to develop fully immediately after the traumatic impact. It can also develop over time. For this reason, neurosurgical head patients require an intensive care bed to be reserved so that they can be monitored on the day of their open head surgery. If there is no free space on the intensive care unit (ICU), surgeries are cancelled. This is of relevance for a hospital's ICU capacity. Relatives of neurosurgical patients often perceive the end of the surgery as marking the end of the risk. From a medical point of view, this is wrong.

Severe swelling can sometimes develop up to 14 days after incidents and, despite the late onset, lead to brain death.

Source: Öhman

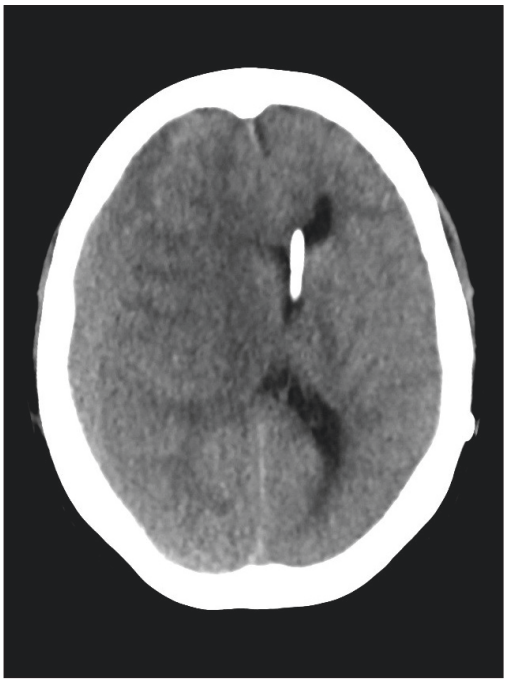

**Figure 1: In modern imaging, the images are viewed by definition from below, so that the left side of the image shows the right side of the patient. Visible in the image here is an acute subdural bleed. In this hemisphere of the brain, the black areas of the normal fluid spaces are completely swollen. In the other hemisphere, these are visible. The white structure represents a catheter draining the fluid.**

This can also happen in patients with trauma, violent traumas or accidents and also for mild TBIs after a simple accident. This is the reason why medical doctors, as a general rule, prescribe rest after a head trauma and patients are required to stay in hospital for 24 hours. Most of the bleeds occur within the first 24 hours after trauma.

As a brain edema can develop over time, depending on the severity of the impact and the location of the swelling, patients are often admitted directly into a clinic, ideally one that is equipped with a neurosurgery.

The late onset of malignant brain swelling is also described as "talk-and-die-syndrome". If the swelling of the brain is progressing, time to treatment becomes a key factor for the damage to the brain tissue. Therefore, these patients belong in hospitals that have a neurosurgical department and are able to perform surgery in these cases without delay.

Medically, several therapy options are available for treating brain edema. By inserting a probe into the brain, the brain pressure can be monitored on a neurosurgical ICU. Surgery can also be performed to reduce an elevated brain pressure. In these cases a craniotomy is performed. A part of the skull is removed to create space for the swollen brain and to reduce the risk of this soft tissue being damaged by compression against the hard bone. Later on, the explanted part of the skull is reimplanted or replaced.

The risk of a large rise in brain pressure lies in a brainstem compression. Dr George Kellie and Alexander Monro secundus of Craiglockhart and Cockburn, a Scottish surgeon and a Scottish anatomist, described the relations of blood, CSF and brain in the fixated and incompressible surrounding of the skull. All three compartments are related, which means that if the blood is increased, e.g. through a bleed, the CSF and the brain are compressed outside the skull cavity. This leads to a compression of the brain stem against the foramen magnum, the largest opening of the skull base. The brainstem contains many important areas, so this condition is dangerous and can lead to death if left untreated.

Although the mechanical principles of increased intracranial pressure were already described in the 18$^{th}$ century, it took until the second half of the 20$^{th}$ century for the substance on the inside of the skull to be documented in the living human through computerised tomography (CAT-Scan). The development of modern imaging methods enabled physicians to see inside the skull and the spinal column without damaging the structures.

Source: Öhman

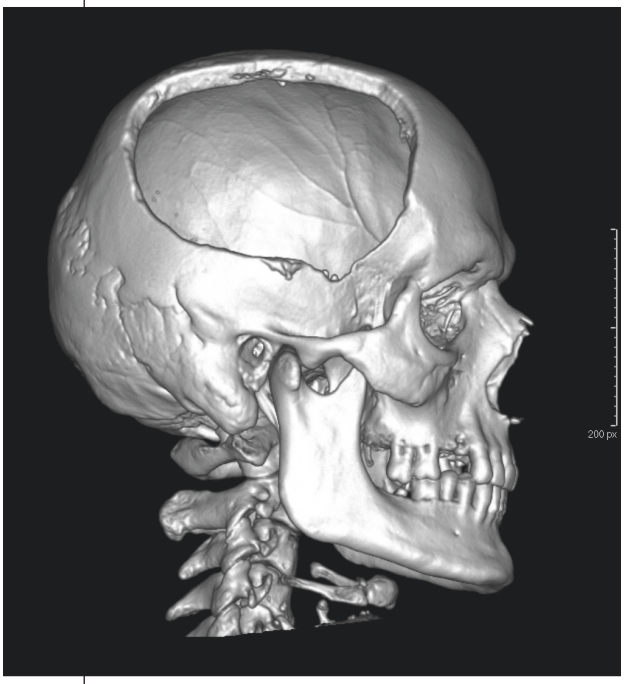


**Figure 2: Craniotomy of the skull to relieve pressure**

## EFFECTS ON FORENSIC SCIENCE

If the clinical knowledge is set in relation to the forensic sciences, it can be seen that the clinical side of TBI affects the crime scene reconstruction, the investigation of statements and the judicial procedures in court.

### Effects upon crime scene reconstruction

As described, many cases involving a TBI do not immediately lead to an impairment of the victim. This means that the victim in these cases might be able to move for a while after the attack. This does not mean that the victim is able to request help in any way. TBI is associated with a reduction of consciousness and can also happen without or only with little physical disability in the beginning. In these cases, changes to the original crime scene can be made by the victim.

It is in the nature of a murder that the victim often remains at the crime scene, whereas the perpetrator removes himself from the scene. For this reason it has to be taken into consideration during crime scene reconstruction that, in cases involving death due to TBI, crime scenes might be altered by the victim in the aftermath of the murder, even if the victim is later found dead at the scene. This can also happen at a time when the perpetrator was already gone.

Biological traces, like unknown liquids, might also be a result of the TBI, e.g. through vomiting, which is a symptom of increased brain pressure (ICP). Traces might be created after the incident itself. The time windows for victim movement can range from minutes to several hours. This is critical knowledge for crime scene reconstruction.

### Effects upon interrogations

TBI also has an effect upon statements of injured persons, which can be seen in the following example:

A man showed aggressive behavior in a club and was therefore cautioned to calm down by the local security service. Later during his stay, he behaved aggressively again towards other customers and was therefore thrown out of the club. When he left, he threatened to return with a weapon and ran away. The security service took a car and followed the aggressive man. At one point two of the people in the car got out of the car and followed the person. The other ones remained at the car, which was confirmed by neutral witnesses. The aggressive man was knocked to the ground and sustained a concussion. Although several witness statements confirmed that two people were following the person and the others remained at the car, the two people who followed and one person who initially remained at the car were sentenced. A reason for this court's decision was that the injured remembered these three people standing around him.

Crime scene reconstruction showed two injuries, which were consistent with the actions of the two men who had left the car first. Crime scene reconstruction did not show any third injury or suspicion of a third person present at the time of the direct incident. Therefore, the most probable crime scene hypothesis was that there were two incidents that were committed by the two people who left the car first and that, due to the TBI, a small part of the victims memory was lost. The situation, in which all of them were standing around the injured was also described by several witnesses, but to a later moment in time.

So this shows the possible influence of TBI upon statements. In cases of TBI not only the memory of the complete incident might be missing, but also parts can be missing. The memory is therefore connecting two parts without being aware that another part is missing. We call this effect the Broken-Continuity-Effect (BCE). It is the partial memory loss during an incident and the subconscious connection of two separate parts into one story line. An important aspect of the BCE is that no additional, unreal information is added to the memory. One part of the memory in the middle of the time line is missing and therefore the end of the first part is attached to the beginning of the next part, present in the memory. The continuity is broken.

This means that in those investigations both perpetrator and victim might give reliable statements, although they seem to be contradictory. In court, a polarisation is often considered, meaning that one party is lying in cases of contradiction. But in these cases, both parties are presenting reality; it is just that the continuity of the injured person is missing. In cases of TBI, it is important to be aware when neutral witnesses describe parts of the injured person's statement at a later time during the incident. In these cases the BCE needs to be reconsidered for crime scene reconstruction.

**Effects upon forensic, medical examination in the living**

Brain trauma is often assessed too mildly by medical doctors without clinical, neurosurgical experience such as forensic pathologists (compare to Brodbeck et al. 2017, Brodbeck et al. 2018). This can often be seen in the assessment of smaller bleeds into the brain or the meninges. Small bleeds can be quickly resorbed like bruises and are usually no longer seen in a control CAT-Scan within a few days. As already described in the first article of this series, the danger lies not only in the symptom, the bleed in the tissue. Although the bleed itself produces the symptoms and often poses an acute danger for a patient. The second danger lies in the injury of the vessel, which cannot be seen in modern CAT-Scan or MR-Imaging and which might lead to a new bleed. Until today it is not possible to image the vascular walls. Angiographic imaging in radiology is produced by filling a vessel with contrast medium and additionally via the exit of

Source: Silke Brodbeck

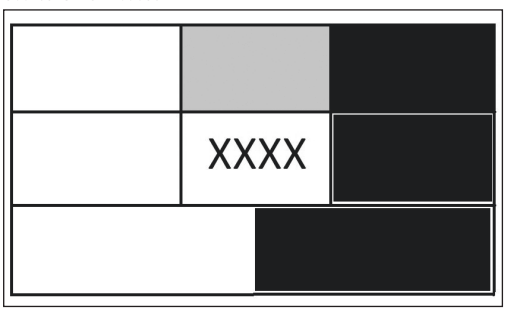


**Figure 3: Possible change in the memory structure in the event of traumatic brain injury with retrograde amnesia. At the top is regular memory consisting of three components (white, grey and black). In the middle, due to the retrograde amnesia, the central segment is damaged so that lower line remains in the memory and the white and black segments are placed together in omission of the grey portion.**

the marked blood into tissue or the closure of a vessel, which shows a stop to the marked blood. But the wall of the vessel is never shown directly, only the filling of the vessel can be imaged.

From a neurosurgical point of view, all humans who suffer a bleed into brain tissue or in the meninges need to be considered life-threatening, even when the blood is resorbed quickly and the patient is transferred to a normal ward. Brain edema and resulting brain death can also occur two weeks after a mild trauma. So bleeds in the skull are always a life-threatening condition and need to be taken seriously.

Examinations of forensic pathologists for injuries are often conducted shortly after the incidents themselves. In terms of the documentation of hematomas or smaller injuries this approach is correct. But for the assessment of traumatic brain injuries, a subsequent worsening of the injury needs to be considered. Usually, this is only recognised in cases where the patients are deteriorating so much that additional neurosurgical hospital treatment becomes necessary.

Another topic is that trauma-induced symptoms (such as cognitive impairments, e.g. concentration or memory disorders, hypersomnia and others) are often wrongly diagnosed as post-traumatic stress disorder (PTSD). These symptoms are often caused by TBI. The difference is in the therapy. In cases of organically caused symptoms, no psychiatric or psychotherapeutic treatments will work. Although it should be noted that PTSD is often associated with TBI in cases of attempted murders and also requires adequate treatment on its own.

It should also be noted that this is a problem not only in forensic pathology, but also in other areas of medicine. In cases of severe injuries to other parts of the body, a mild TBI often remains undocumented. TBI must always be documented, as proof may be required for insurance purposes, for example.

## OUTLOOK

Clinical neurosurgical factors of TBI can impact investigations of assaults and homicides. Unfortunately, they are often overlooked or incorrectly assessed. TBI can severely influence statements given by injured persons, the crime scene reconstruction and the medico-legal clinical examinations of humans.

In crime scene reconstruction, traces might be found at the crime scene that were caused by the dead person himself after the incident.

Statements might be put together with parts missing, which, in consideration of the BCE, leads to the fact that contradictory statements can be both valid, even when they are not identical. This causes problems, because in jurisdiction the dual concept of “truth and lie” is assumed.

Finally, it should be noted that TBI can also lead to brain death within a timeframe of two weeks and that a medical examination at a later point in time might be of importance from a legal perspective in some cases. For these reasons, it is important to know these effects and to forward these cases to a trained specialist with knowledge in this field.

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