Cranial fractures caused by blunt trauma

Characterization of a medico-legal material and assessment of post-mortem Computed Tomography

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PhD thesis

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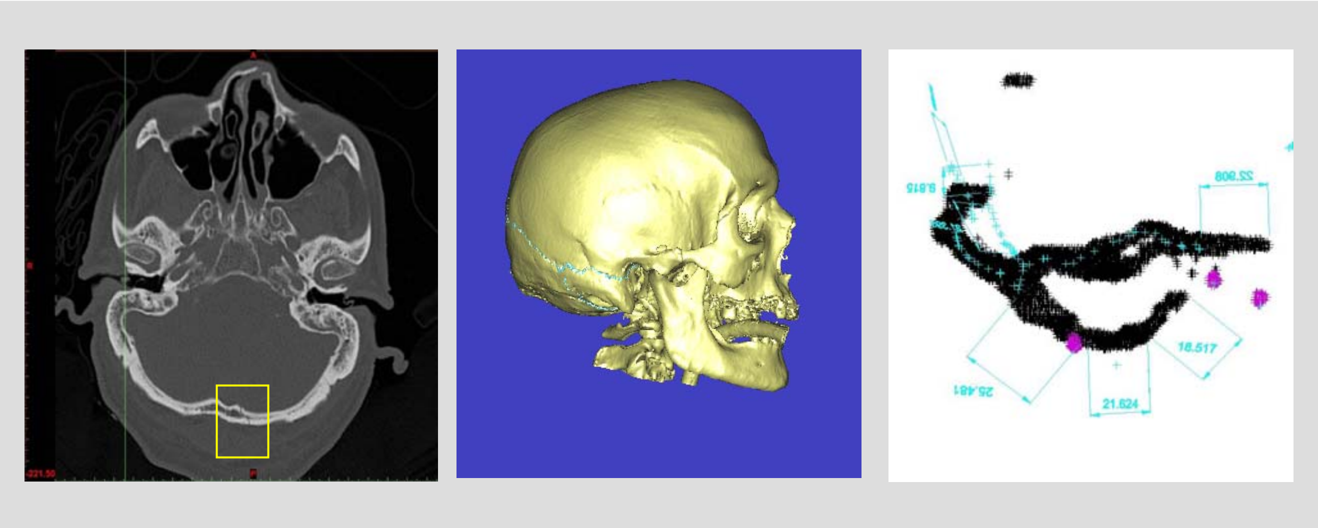
Characterization of a medico-legal material and assessment of post-mortem Computed Tomography



Academic advisor: Professor Niels Lynnerup

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Christina Jacobsen,
Copenhagen 2009

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Aims of the thesis

I. The aim of this study was to provide the summary statistics and an up-to-date overview of all cases with cranial fracture caused by blunt trauma regardless of cause of death as encountered in a Danish medico-legal material. The focus was on basic case data, including basic pathological description of the lesions and fractures.

II. This study aimed at characterizing the pathology of cranial fractures caused by blunt force by focusing on the skull fractures, the scalp lesions and the trauma type. The overall aim was to improve our understanding of cranial fractures based on a contemporary medico-legal autopsy material and thereby provide up-to-date knowledge for basic forensic interpretations (including post-mortem forensic radiology) preventive measures and biomechanical studies. To achieve this, we related observed scalp injuries to the cranial fractures on a case-by-case basis and hence estimated the scalp injuries as point(s) of impact. We then compared the fractures and impact patterns with cause and circumstances of death, with a special focus on traffic accidents and falls.

III. The aim of the third study was to analyze the agreement concerning the anatomic localization and distribution of cranial fractures and brain injuries as they were diagnosed firstly by CT and secondly by the following autopsy.

IV. In study III it was demonstrated that it may be difficult to visualize non-dislocated fractures of the cranium on CT scans performed in a routine setting, especially when the fractures are located in the cranial base. We therefore examined in detail exactly how a fracture seen on CT scans match autopsy finds. To this end we performed a detailed analysis of 14 cases with cranial fractures by carefully recording the fractures as diagnosed on CT scans post processed with Multiplanar reconstruction (MPR) (1) and Maximum Intensity Projection (MIP) (2), as well as by detailed recording of the fractures at autopsy (drawing and photos). We further tried to quantify the differences by tracing the fractures as seen at autopsy using a 3-dimensional digitizer and merging this 3-dimensional data set with a 3-dimensional reconstruction of fractures diagnosed on CT scan.

Introduction and background

Injury is a leading cause of death in the young and middle aged in the western world (3) and blunt trauma to the head occurs in many trauma types. In most western countries head injuries are mainly caused by traffic related injuries (4). However, in the field of forensic pathology head injuries are caused by many kinds of trauma types and the forensic pathologist is expected to have a sound knowledge about the epidemiology, trauma type and mechanism and resulting extra cranial, cranial and intracranial injuries.

Engberg et al. (4) reported that the Danish incidence rate for cranial fractures was 7.1/100.000 in the years 1991-1993. The annual incidence rate for patients hospitalized for brain injuries is approximately 157/100.000, with an annual mortality rate for brain injuries of approximately 10.7/100.000 (4). A number of epidemiologic studies regarding head and brain injury exist (3;5-20). To our knowledge there are only very few recent studies regarding cranial fractures caused by blunt trauma to the head and the corresponding trauma type (21;22) and no recent studies focus on the cases constituting the medico-legal material. **In the first study the forensic summary statistics of all cases with cranial fracture in the Danish medico-legal setting from 1999-2004 are presented.**

The treatment and pathology of head injuries in general and specifically cranial fractures has fascinated the medical world for centuries. Hippocrates's treatise "On Wounds in the Head" and "On Injuries of the Head" (cited in (23)) both elaborated on the treatment of head injuries and focused on a classification of cranial fractures and the weapons or objects causing them. Hippocrates knew that the appearance of scalp injuries and cranial fractures could be of importance for determining impact characteristics (23). Knowledge of the traumatic injuries associated with different trauma types still forms the basis for interpreting traumatic forces in blunt head injuries today, both as regards skull fractures as well as intracranial lesions. The anatomic localisation and direction of a cranial fracture may provide information about a possible site of impact and thereby important information about force directions and associated intracranial injuries (24;25).

Most of today's knowledge about cranial fractures, the causative trauma mechanisms and involved trauma types is from studies carried out in the beginning and middle of the last century (26-31). Since then most studies have focused on specific trauma mechanisms, trauma types and the concomitant injuries (22;32-55), e.g. for developing preventive and protective measures, with only very few studies looking at cranial fractures and the trauma type in general (21;22), a fact which has also been noted by others (56). In the last decades especially biomechanical studies have been carried out to develop cranial models for analyzing head injury (38;57-64).

To our knowledge there are no studies on a contemporary medico-legal autopsy material linking the anatomic localisation, orientation and extent of cranial fractures with the impact regions for different trauma types. **In the second study cranial fractures caused by blunt force were characterized by focusing on the cranial fractures, the scalp injuries and the trauma types, in order to provide up-to-date knowledge for basic forensic interpretations, preventive measures and biomechanical studies.**

The evaluation and demonstration of the causative trauma mechanism and trauma type by analyzing traumatic injuries is an important part of the forensic pathologists every day work and demands diagnostic accuracy and precision. Until a few years ago, the demonstration of traumatic head injuries was mostly done during autopsy supplemented by radiography and histology. New diagnostic possibilities in forensic pathology have been provided with the introduction of Computed Tomography Scanning (CT) and Magnetic Resonance Imaging (MRI) and CT scanning of bodies prior to medico-legal autopsy has become a powerful tool in several forensic institutes throughout the world (65-68). Internationally there have been a number of studies regarding the use of both clinical and post-mortem CT and MRI in forensic pathology (20;66;67;69-78). Previous studies have illustrated both advantages and limitations regarding these subjects (20;66-73;75-78). Indeed, there may be a number of advantages to performing a CT scan before a medico-legal autopsy. The radiological imaging of the head by CT and MRI is suitable to visualize lesions of especially bone, but also soft tissue and cerebral pathologic changes or lesions (79). Fractures, intracranial haemorrhages and hematomas can be demonstrated both 2- and 3-dimensionally, providing a general overview of simple as well as complex lesions, e.g. wound tracks in fire arm injuries or large fracture systems (67-69;80;81). The scans are non-invasive and have been claimed to be observer-independent and objective (66).

At the forensic institute in Copenhagen post-mortem CT scanning has been performed routinely since 2002 and MRI since 2004. It has become evident that the forensic image acquisition and image-based diagnostics serve certain purposes. Aside from the great advantages of being able to store the acquired material indefinitely for forensic evidence, the images provide the pathologist prior to the autopsy with information of which lesions or pathologies might be expected. Often 3-dimensional reconstructions are performed to visualize the coherence between lesions or pathologies and the body (soft and hard tissue) e.g. wound tracks in fire-arm injury; or blunt force injuries. These reconstructions are as useful to the pathologist as to lay personnel (e.g. police, judicial system) for visualizing the complexity of lesions. The images are used both in the daily routine work and occasionally in court to demonstrate the lesion context. But in the first few years of using CT in Copenhagen a lack of coherence between head injury diagnoses based on the CT images and the autopsy diagnoses became apparent. To clarify this issue a systematic definition and analysis of the diagnostic discrepancies regarding head injuries by CT scan as opposed to autopsy was undertaken. **The third study analyzes the agreement concerning the anatomic localization and distribution of cranial fractures and brain injuries as they were diagnosed firstly by post-mortem CT and secondly by autopsy.**

One of the emerging, interdisciplinary investigative methods in the forensic sciences is the usage of biomechanical models of the head for analyzing injury mechanisms (82-84). Due to the nature of the technique, CT scanning allows for the collection of spatial, digital data of the cranium, which potentially could be used in the development of new analytical tools in forensic pathology and injury biomechanics (60;85). CT scan data have previously been used for creating biomechanical models (86-88) of body parts, e.g. the cranium (59;89-91), one of the advantages being that the data represent the complex anatomic structures of the cranium of the single individual. The possibility of being able to develop either standard or individual cranial models subject to retrograde trauma analysis with Finite Element Analysis could open up for new prospects regarding medico-legal case work both in adults and children.

In the third study it was shown that it may be difficult to visualize non-dislocated fractures of the cranium on CT scans performed in a routine setting (92), especially when the fractures are located in the cranial base. When this is combined with the results of the second study, which showed that the skull base is involved in nearly 90% of all cranial fractures, it becomes evident that forensically important information about the whole fracture system and possible impact points may then be lost in the cases in which these fractures provide clues about the causative forces. In order to be able to use CT scan data of victims with minor fracture systems in future retrograde biomechanical modelling, it is necessary to not just examine the overall diagnostic agreement between CT scanning and autopsy, but also to examine in more detail exactly how fractures seen on CT scans match autopsy finds.

Therefore, in the fourth study, a detailed analysis of 14 cases with cranial fractures diagnosed on CT scans post processed with Multiplanar reconstruction (MPR) (1) and Maximum Intensity Projection (MIP) (2) and at autopsy was performed. The differences between the fractures as seen on CT scan and autopsy were established by using 3-dimensional examination modalities on both data sets, including digitizer based tracings of the actual fractures as seen at autopsy.

List of papers

This thesis is based on the following papers:

I. Jacobsen C, Lynnerup N. Cranial fracture caused by blunt trauma to the skull - A retrospective analysis of medico-legal autopsies in Denmark 1999-2004 - *accepted for publication in Scandinavian Journal of Forensic Sciences*

II. Jacobsen C, Lynnerup N. Cranial fracture characteristics and their impact regions in blunt trauma - *manuscript ready for submission*

III. Jacobsen C, Lynnerup N. Craniocerebral Trauma - Congruence between Post-mortem Computed Tomography Diagnoses and Autopsy Results - A 2-year retrospective study - *submitted*

IV. Jacobsen C, Bech BH, Lynnerup N. A comparative study of cranial, blunt trauma fractures as seen at medico-legal autopsy and by Computed Tomography - *submitted*

The papers will be referred to by their roman numerals in the text.

Paper I - Cranial fracture caused by blunt trauma to the skull - A retrospective analysis of medico-legal autopsies in Denmark 1999-2004

Material and methods

The study is based upon medico-legal autopsies performed at the forensic institutes in Denmark at Copenhagen, Århus and Odense, in the period 1999-2004. In this 6-year period a total of 8682 forensic autopsies were performed at the institutes; 4805 in Copenhagen, 2714 in Århus and 1163 in Odense (overall male/female ratio 2.5:1). The cases were selected by using databases at the institutes. Cases with fractures of only the facial skeleton, intracranial lesions without cranial fractures, and cases involving sharp trauma or cranial gun-shot wounds were excluded. This resulted in a total of 428 cases (Copenhagen 170/Odense 92/Århus 166), equivalent to ~5% of all the autopsies in the period.

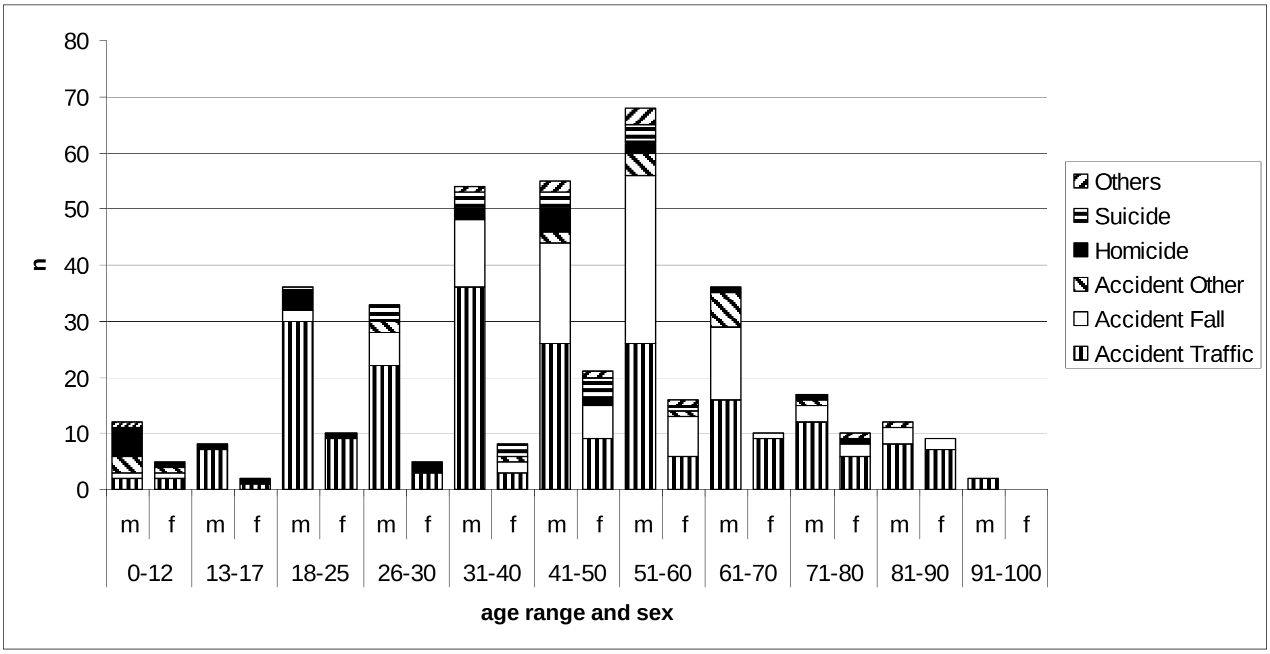
By reviewing the autopsy reports, including the forensic toxicology report, we registered basic data, including the circumstances regarding the trauma, the autopsy findings regarding fractures in the neurocranium, the associated scalp lesions and the macroscopic intracranial lesions. If a microscopic examination of intracranial lesions was performed the results were not registered. The results of a forensic toxicology analysis (400 acid, neutral and basic drugs, tetrahydrocannabinol, cocaine, benzoylecgonine, methadone, amphetamines, opiates, benzodiazepines, buprenorphine and norbuprenorphine) and/or analysis of blood alcohol concentration (BAC) were registered. Results of a possible hospital analyses were registered in the autopsy reports and in these cases a forensic toxicology analyses had not been performed. All analyses were included for the general overview. For the detailed description of the results only the forensic analyses was included.

The cases were grouped by the manner of death into accident, homicide, suicide, natural and undetermined. These groups were sub-grouped into different types of trauma: Traffic related deaths, falls and the related height, hit/struck/crushed by blunt object and other trauma type.

Results

Sex and age distribution

The material comprised 330 males (age span: below 1 year of age to 93 years; median: 40 years) and 98 females (age span: below 1 year of age to 89 years; median: 59 years) with a male:female ratio of 3:1 (see figure 1). This disparity between the sexes was evident throughout all the age groups until the seventh decade, with a relatively larger male proportion killed in accidents and homicides. From 71 years of age the disparity between the sexes diminished.



"Others" includes natural deaths and undetermined manner of death.

Figure 1. The manner of death distributed by age range and sex.

Manner and cause of death

The largest group of cases were accidents (see figure and table 1), which comprised traffic accidents (n=242), falls (n=109), trauma by blunt object (n=14) and other accidents (n=7). A cranial fracture was sustained by 37.5% of all the medico-legally autopsied traffic related deaths (n=651) in this period, while the other accidents, including falls caused cranial fractures in 4.5% of all the medico-legally autopsied falls and other accidents. The share of traffic accidents was proportionally greatest in the age ranges 18-40 years. Among cases above 40 years of age, traffic accidents and the other accident types were represented evenly. In the age group 81-90 the role in traffic changed, especially for females, from using motorised vehicles and bicycles to being a pedestrian with an increase in falls and being hit by motorised vehicles. Falls occurred throughout the age ranges; there were a few falls below the age of 12 years and a peak of falls at the age of 51-60 years.

The homicide cases with cranial fracture comprised 4.5% of the total material (n=26/428) and in most cases the head had been hit/struck with a blunt object, jumped upon or kicked (73%). Another mechanism was falls (~15%) in the course of interpersonal violence and three cases had been registered as "other mechanisms". Roughly one third of the homicide cases were female (n=7), which were distributed evenly through the age ranges, unlike the males in which a higher number of homicides occurred in the age range of 0-12 years and 41-50 years.

Of the 20 suicide cases (3.5% of the total material), half committed suicide by jumping from heights and half occurred in a traffic setting (four were car drivers, five were hit by train, one was hit by a truck). This occurred in the age ranges of 18-60 years for males and 31-60 years for females. There were three cases of natural death which all comprised sudden deaths due to a natural disease. In these cases the cranial fractures were the result of falls in relation to death and the cause of death was nonviolent. There were seven cases in which a manner of death was not determined; in three of the seven cases there was a suspicion of homicide versus accident, in one case suicide vs. accident and in three cases natural death vs. accident.

Overall, craniocerebral lesions were the sole cause of death given in approximately half the material (see table 1) and in nearly all the remaining cases poly trauma, e.g. the craniocerebral lesions were combined with substantial lesions of other organ systems. There was no difference in the cranial fracture characteristics of these two groups.

Characteristics	**n=428**
Manner of death:	
Accidents	*372*
Homicides	*26*
Suicides	*20*
Natural death	*3*
Undetermined	*7*
Cause of death:	
Craniocerebral lesion	*233*
Craniocerebral lesion and other lesions	*190*
Undetermined	*5*
Trauma type:	
Traffic:	
Car occupant	*103*
Pedestrian	*53*
Bicycle riders	*39*
Motorcycle riders	*32*
Other traffic situations	*26*
Falls/jumps from heights:	
Ground level	*48*
2 - 3 metres	*32*
3 - 5 metres	*16*
above 5 metres	*19*
No height known	*15*
Hit/struck by blunt object and/or interpersonal violence:	
Hit/struck by blunt object	*34*
Blows and kicks	*4*
Other:	8

Table 1. Characteristics of the included cases: manner of death, cause of death and trauma type.

Alcohol and substance abuse

Forensic toxicology, including BAC analysis was performed in 207 cases. Furthermore in 107 cases a BAC analysis only was performed. In additional eighteen cases, hospitals had performed a BAC and toxicological analysis. Based upon hospital and forensic analyses it was found that about half of the tested individuals (n=18/134, 48.8%) tested positive for various substances (see figure 2), with an overall male: female ratio of 6.5:1. For males there was a fairly even distribution throughout the age ranges until 60 years, whereas the number of females testing positive increased throughout the age range of 41-60 years. The BAC was above the legal driving limit of 0.05% in 40% of the cases (n=122/314).

Overall 116 individuals had a known history of alcohol abuse (n=83), illicit drugs (n=17), or a combination thereof (n=12), or of alcohol in combination with prescribed drugs (n=4). Half of the alcohol abusers tested positive for alcohol and/or illicit or prescription drugs at the time of death. Likewise most of the illicit drug abusers (82.4%) and half (56.3%) of the mixed substance abusers tested positive for various substances.

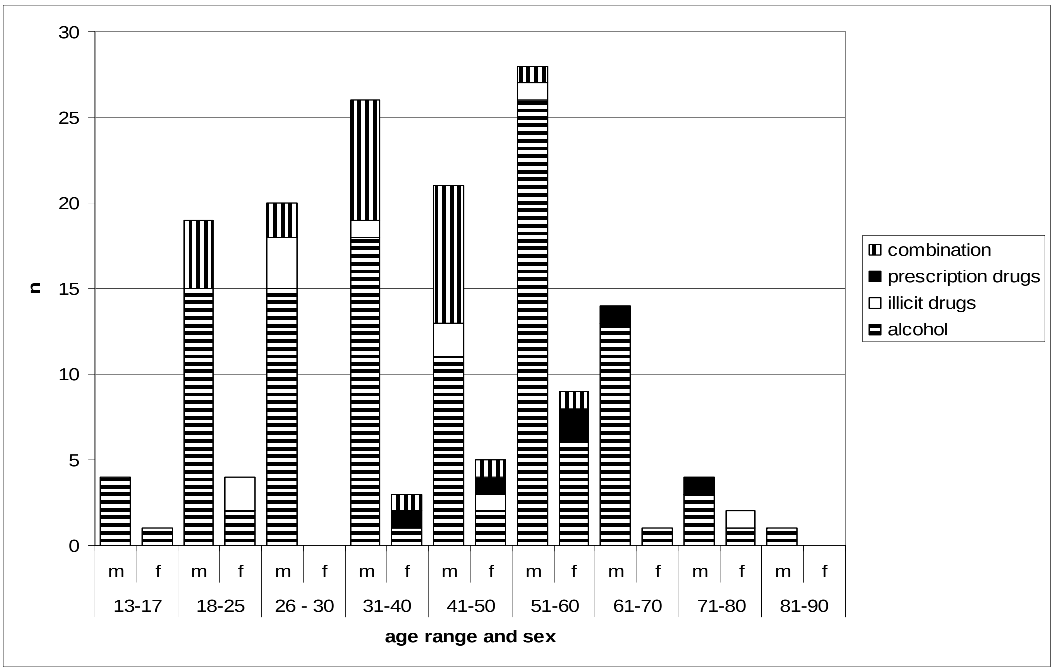


Figure 2. Number of cases with a positive test for alcohol, illicit drugs and prescription drugs distributed by age range and sex.

Trauma type: Traffic

In our material most cranial fractures were caused in traffic (n = 252 cases) (see figure 3). Car accidents formed the largest group with a declining frequency after the 31-40 year group. The car drivers were the car occupants which most often underwent a medico-legal autopsy. The second largest group were pedestrians (n=53), mostly hit by motorised vehicles, with a peak at the age of 18 to 30 (n=11) and 81 to 90 (n=11). Motor cyclists and bicycle riders (n=32/39) sustained cranial fractures most often by being hit or hitting other vehicles (n=23/30). They were distributed nearly evenly throughout the age ranges. There was seldom information whether cycle riders had used protective helmets. The group of other traffic related deaths consisted amongst others of plane (8 accidents) and train crashes (3 accidents/5 suicides). A BAC above the legal driving limit was found in 25 car drivers and 9 motor cyclists. Also 19 pedestrians and 7 cyclists tested positive for alcohol. Seven of the road users tested positive for illicit drugs.

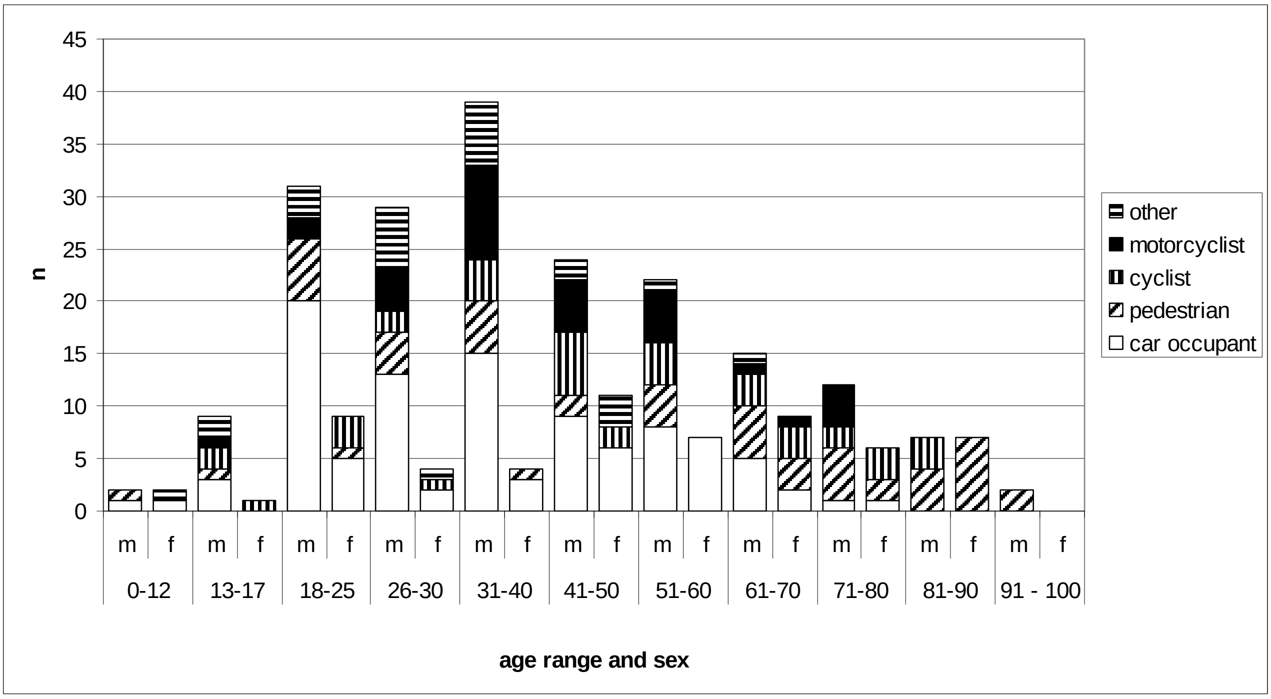


Figure 3. The activity during a traffic accident distributed by age range and sex.

Trauma type: Falls

Most falls had been classified as accidents (n=109/129). There were also ten suicides, five homicides, three natural deaths and three cases in which the manner of death was undetermined. In 116 cases there was a height specification (see table 1). Ground level falls and falls down stairs constituted 67.5% of all the falls and occurred mostly in domestic settings. Falls from buildings (n=10), ladders (n=4) and outdoors (n=1) were also represented. The suicidal jumps from heights were mostly from buildings, but also bridges and, in one case, a staircase. The fall height varied between 3 m to above 20 m. The individuals tested positive for alcohol in 38 of the fall cases (34 male, 4 female) and this was especially seen in ground level falls and falls involving stairs. Of these individuals 63% were known alcohol and/or illicit drug abusers (n=21 alcohol, n=3 alcohol and illicit drugs).

Trauma type: Blunt interpersonal violence or violence by/with blunt object

This group (n=38, male=29, female=9) comprised 16 accidents and 22 homicides.

The accidents were characterised by several different trauma mechanisms resulting in crushing of the head by heavy objects (e.g., a television, tree-branches) and other mechanisms. Five of these accidents were work-related and five happened during leisure activities outdoors.

Interpersonal violence (blows and kicks) or a blunt object was the mechanism in 22 homicides. Five of the cases were female adults and ten were male adults while the remaining cases were under the age of 14 years. A blunt object was used in 10 of the homicides. The type of object used varied greatly (e.g., a mannequin arm, a wooden log) and in five cases no information about the object used was available. Ten cases were with interpersonal violence, of which three cases were with witnessed jumping on/punching/ trampling or kicking to the head. Three children under the age of 14 died in the course of an extended suicide in which their father induced blunt trauma to their heads and afterwards caused an explosion of their home. (The cause of death could not be established in these cases.) Seven individuals tested positive for alcohol and three of the seven also for illicit drugs. The group also comprised six infants under the age of 12 months (two accidents and four homicides). Two sustained accidental cranial fractures by manual or instrumental force on the head during child birth. Four infants were killed in homicides and sustained their head injuries by being hit against an object, with an object or by being punched/kicked by primary and secondary caretakers.

Trauma type: Other

In eight cases there was no information about how the cases had sustained the craniocerebral injuries.

External cranial lesions

Almost all cases (398/428) had one or several scalp lesions. A total of 946 single lesions were registered (see table 2). The most common lesions were sugillations or subgaleal hematomas, but severe burns (e.g. car occupants) and partial amputations also occurred. Bleeding from the auditory canal was in nearly all the cases (n=94) associated with a basilar cranial fracture. The mono- or biocular hematomas were associated with fracture of the bones comprising the anterior fossa in approximately 80% of the cases. In 30 of the cases (19 traffic related/10 falls/1 accident by blunt object) external lesions were not reported in the autopsy reports. Eleven of these cases had been hospitalized and treated prior to death and six survived for more than three days, which could have resulted in healing of minor external lesions prior to the autopsy. This means that in 19 cases no external lesions were registered, but it is possible that they were not correctly identified and registered by the pathologist.

External lesions and signs of fracture	n
Contusion wounds	*244*
Excoriations	*162*
Sugillations/subgaleal hematomas	*502*
Other lesions (e.g. burns)	*38*
Bleeding from auditory canal	*96*
Mono- or biocular hematomas	*68*

Table 2. The number of external lesions and signs of fracture.

Fractures of the neurocranium

Blunt trauma to the neurocranium had resulted in 428 fracture systems which consisted of a variety of different fracture types divided into linear fractures and other fracture types (93) (see table 3). The linear fractures comprised ~60% of the total material. The other fracture types ranged from involving small areas of the theca, e.g. depressed fracture to massive comminute fractures. Some of the other fracture types were combinations of the fracture groups, e.g., depressed fractures combined with multiple fractures or linear fractures and were therefore grouped separately (table 3).

Fractures of the neurocranium	n
Linear fractures	
Anterior-posterior orientation	*84*
Side-to-side orientation	*107*
Oblique orientation or combination	*60*
Subtotal	*251*
Other fracture types	
Depressed	*22*
Multiple	*22*
Spider web	*3*
Ring fracture	*15*
Comminute	*62*
Combination	*42*
Inconclusive	*11*
Subtotal	*177*
Total	428

Table 3. The classification and number of cranial fractures.

The linear fractures were anatomically generally located equally in the base or both the base and the theca, while only a few fractures were located solely in the theca (see table 4). The other fracture types mostly involved both the base and the theca. The comminute fractures always involved both, while especially the ring fractures involved only the base. The so-called inconclusive fractures (in table 3) were cases in which the fracture description from the autopsy report did not allow a certain classification.

	Base and theca	Base	Theca	Total
Linear fractures	111	120	20	251
Other fracture types	126	34	17	177
All fracture systems	237	154	37	428

Table 4. The anatomical localisation of linear fractures and other fracture types.

Intracranial lesions

In 371 cases 998 intracranial lesions were registered macroscopically during the autopsy (see table 5). Contusions and subarachnoid haemorrhages were found in approximately 70% of the cases while epidural haemorrhages occurred in only 5% of the cases. The frontal lobes sustained one-third of the contusions, while the temporal lobes and the cerebellum were affected in approximately 25% and 14% of the cases respectively. Subarachnoid haemorrhage involving the hemispheres was seen in 42% of the cases, while localised subarachnoid haemorrhages involved the frontal and temporal cerebral lobes in approximately 14% of the cases respectively and the cerebellum in approximately 17% of the cases. The subdural haemorrhages were distributed evenly over both hemispheres, while epidural haemorrhages were more common over the right hemisphere. Approximately 80% of the epidural haemorrhages were located over the right hemisphere and were associated with mainly linear fractures of the right temporal and/or parietal bone and lesion of the middle meningeal artery. Cerebral haemorrhages occurred especially in the frontal lobes and the cerebellum.

	SAH	EDH	SDH	Contusion	Laceration	Haemorrhage	Total
Frontal lobes	56	0	0	119	30	12	217
Temporal lobes	55	0	0	74	23	6	158
Parietal lobes	34	0	0	22	14	6	76
Occipital lobes	14	0	0	37	11	1	63
Cerebellum	69	0	0	45	19	15	148
Right hemisphere	86	16	46	16	7	6	177
Left hemisphere	81	4	52	7	9	6	159
Total	395	20	98	320	113	52	998

Table 5. The anatomical localisation of the registered intracranial lesions.

Discussion

While there are many epidemiological studies about head trauma and traumatic brain injury (3-13;15-19), we have found only few recent studies about cranial fractures (21;22). Indeed, most of the extant knowledge about the pathology of cranial fracture arises from studies carried out in the beginning and the middle of the last century (26-28;93;94). The epidemiological data from our medico-legal material was compared to studies based both on clinical data and death certificates regarding head injuries and traumatic brain injuries (3-13;15-19), and studies on cranial fractures (21;22;26-29;94).

Validity

Our study was intended to provide an overview of cranial fractures caused by blunt force in a medico-legal material. We focused only on cranial fractures regardless of cause of death and the results naturally have to be interpreted with this in mind. The medico-legal autopsies in Denmark are performed on request of the police in cases of interest according to the legislation. This material is therefore characterized by comprising only a fraction of the deaths by accident or suicide, namely when there is doubt about the manner or cause of death. As a consequence of this the material reflects only a portion of the deaths with cranial fracture by blunt force in Denmark which, amongst others, is reflected in the distribution of the trauma type and age, e.g. there were only a few elderly in our material. BAC analysis was performed in most cases (75%), of which 40% were positive, while forensic toxicology analysis was performed in half of the cases, of which 20% tested positive. A selection bias is thus introduced by the police not requesting analysis in all cases.

Manner of death and trauma type

In some aspects our material reflects the sex and age distribution of head injuries in Denmark and other countries (5-9;16;18;19;22). As others, we also found a proportional peak in case numbers in the young children, the young adults and middle aged, while an otherwise reported increase in the total number of elderly (5-8;16;18;19;22) was not seen. This is most likely explained by a decrease in deaths were medico-legal autopsy was deemed necessary for this age group. The sex ratio is in line with other studies, with a preponderance of males compared to females (3-13;16-19;22). We noticed, however, a levelling out of the sex difference in old age which has been mentioned only in a few other studies (3;6). This probably reflects the composition of the population in general at that age.

Our study shows a peak of cranial fractures caused by traffic accidents in the young adults which coincides with the incidence rate of head injury in other studies (6-8;12;17;18;35). In our study the number of cranial fractures caused by accidental falls is noticeable in the very young and increases through the age ranges, peaking in the age range of 51- 60 years. This is partly comparable to some studies (15;22), although in other studies the incidence progresses further throughout the older age ranges (75+ years) (5-9;11;12;18;19), together with an increasing mortality rate for falls (12). In the mentioned studies the increase in falls substitutes traffic accidents as the prominent trauma type for head injuries, which is not the case in our study reflecting the medico-legal material. Compared to other European countries and the US, a high share of head injuries in Scandinavia were caused by falls (10;11;13;18;19), but head injuries in Denmark are predominantly caused in traffic (4). In studies about the methods used in homicides (95-99) and interpersonal violence in assaults, blunt force was used in 16-36% of the homicides and in most of the assaults (100). The blunt violence was mostly aimed at the head, including the face both in adults (96;99-101) and children (102), mainly by blows and kicks (96;97), although some studies found (95;101), similar to our findings, that a variety of blunt objects were used in approximately half of the homicides. The age and sex distribution of the homicide cases in our study matched the distribution found in other studies with a comparable population (97;102), although we found a preponderance of male cases in the age range <12 years, a tendency which Myhre et al. (15) also found. Only a few suicide cases are represented in our material, but even so the age and sex distribution corresponded to other studies (103-105), although no elderly cases were found in our material. Blunt force as a suicide method (e.g. jumping from heights/in front of motorised vehicles/trains, traffic accident) is not very common internationally (103-105) and has been described as a "hard suicide method" (106). The number of car driver suicides in our material suggests that this method might be more common than expected (107).

Alcohol and substance abuse

One third of the fall cases, 25% of the traffic cases and some of the homicide cases tested positive for alcohol. This has also been found in similar studies of traumatic deaths (35;108;109) and in studies on drugged driving (110). A few of the cases in our study tested positive for illicit drugs which also corresponds to other studies (111;112). Others (108;113) found that head injury severity for blunt trauma did not increase depending on alcohol abuse, while Ingebrigtsen et al. (19) found a tendency towards greater severity. A positive alcohol test is common in fall cases, but regarding ground level falls no increasing injury severity was found even though half the cases tested positive for alcohol (54). Preuβ et al. (52) found that nearly 70% of cases with falls down stairs tested positive for alcohol, which in our study was true for 50% of the cases.

External lesions

The greatest part of the cases sustained external lesions in the course of the trauma to the head, and often there were several lesions per case. It has been found by Yartsev et al. (114) that external lesions of the head may be fairly predictable of cranial fracture or intracranial injury with a positive predictive value of ~80%. In the same study (114) it was also found that bleeding from the auditory canal was highly predictive (95%) for basilar cranial fracture which is in concordance with our material. In our study also mono- or biocular hematomas seemed to be associated with fracture of the frontal cranial base. We also found several cases, distributed evenly across the age ranges, with no external lesions yet cranial fractures of varying severity. Lack of registration by the pathologist or healing of injuries in individuals which initially survived could explain some of the absent injuries and instant death the absence of e.g., sugillations (115). Also the biomechanical trauma circumstances, e.g., the size of impact area, the nature and surface of the impacting material/object are of significance for the causation of external injuries. We are not aware of studies that explicitly have focused on an absence of external injuries on the head despite the application of a substantial amount of force. Kremer et al. (116) found that over half of the included fall cases did not sustain lacerations, in a retrospective study systematically analysing the relation of skull fractures to the Hat Brim Line. However, in their study there was no mention of other external injuries. Hartshorne et al. (54) noted that internal head injuries often were more severe than predicted from the relatively minor external injuries, in an analysis about ground-level falls,.

Fractures of the neurocranium

Linear fractures of the neurocranium caused by blunt force are reported to be the most common cranial fracture in population studies (21), clinical studies (15;117), medico-legal studies (27) and experimental studies (93), which is in line with our study. Also the share of comminute fractures in our study corresponds to other studies (21;27), while there are fewer depressed fractures in our and LeCounts (27) material than in other studies (21;117). This might be explained by the selected medico-legal material and possibly an increased chance of survival with a sustained localised depressed fracture compared to the other fracture types. Ring fractures are known to occur seldom (118;119).

Fractures of only the base are often the result of severe trauma (26;120). In our material the fractures involved only the base in a third of the cases which is similar to other studies which found that this occurred in approximately 20% of the cases (21;121). In contrast to this, Bauer (94) refers to several medico-legal studies which report fractures involving only the base in 60-70% of the cases. Others have found the combination of both basilar and vault involvement to be common, while involvement of only the vault occurs less often (27;28;94). Jennett et al. (121) report in a clinical study that radiological detected vault fractures occurred in 62% of the cases and found less common involvement of both the base and the vault (27%). This might be explained by radiologic difficulties in diagnosing fractures located in the cranial base, especially by traditional X-raying, which can result in minor cranial basal fractures not being diagnosed.

Intracranial lesions

The most frequent intracranial lesion was the subarachnoid haemorrhage followed by cerebral contusions. Similar results were found in a study based on emergency department admissions in which both subarachnoid haemorrhages and contusions were found in approximately 30% of the patients, with increasing incidence with increasing injury severity (12). Kleiven et al. (18) basically reported the same proportions in a Swedish study, but it should be noted that cranial fractures occurred in only 14% of the overall head injury material in Sweden. In contrast, in an American study Freytag (31) found that 12% of the cases in a medico-legal material had suffered severe subarachnoid haemorrhages and nearly 89% lacerations and contusions. Freytag (31) also found a high frequency (63%) of subdural haemorrhages. Other studies (12;18;117;122) have also reported a higher frequency than we find, which amongst other things could be due to difficulties diagnosing the haemorrhages at the autopsy and also due to the selected medico-legal material in this study focusing only on cases with cranial fracture and not all head injuries. The frequency of the epidural haemorrhages is the same as in Kleiven et al.'s study (18), but less frequent than in the other studies (12;31;117). Epidural haemorrhage is generally considered to be seldom (122), probably because fracture of the parieto-temporal bones with subsequent rupture of the middle meningeal artery does not occur very often. To our knowledge no studies have reported an increased occurrence of epidural haemorrhages on either side of the head, although Kremer et al. (116) reported a side lateralization in cranial fractures induced by falls, which were mainly on the right side of the head, as opposed to fractures induced by blows, which were mainly located on the left side of the head. Such a lateralization of cranial fractures was not found in our study.

Paper II - Cranial fracture characteristics and their impact regions in blunt trauma

Material and Methods

This study is based upon medico-legal autopsies performed at the three forensic institutes in Denmark; Copenhagen, Århus and Odense. A total of 8682 autopsies were performed at the institutes during a 6-year period (1999-2004). The cases were selected by using databases at the institutes. All cases with fracture of the neurocranium caused by blunt trauma were selected. This resulted in a total of 428 cases equivalent to 5% of the total sum of autopsies in the period. Cases with fractures of only the facial skeleton, intracranial injuries without cranial fractures, and cases involving penetrating trauma (sharp force and fire arms) were excluded. The material comprised 330 males (age span: 0 - 93 years; median: 40 years) and 98 females (age span: 0 - 89 years; median: 59 years), with a male-female ratio of 3:1 (see figure 1 in study I).

The autopsy findings regarding the cranial fractures, the associated scalp injuries, the manner of death, cause of death and the trauma type were registered by reviewing the autopsy reports. The trauma type was classified as either traffic accidents (with further subdivisions); falls (with further subdivisions depending on height); hit/struck by blunt object by accident or during the course of interpersonal violence or homicide; or as other.

The fractures were classified as either linear fractures or other fracture types, the latter further subdivided into depressed, multiple, ring, comminute, combination and inconclusive (modified after Gurdjian (93)). Further subdivisions pertaining to orientation were also used (24). In addition, the fractures were sorted according to their anatomic localisation: base and vault; base or vault. The fractures situated in the base with a presumed related impact area were classified according to their morphological appearance (following the various fracture types described above) and are not discussed in detail.

The scalp injuries were anatomically classified by dividing the scalp into six general regions: frontal, left and right temporal, left and right parietal and occipital (generally following the vault bones). Injuries could be distributed over a smaller or larger area, thereby involving one or more regions and therefore the extent of the single or group of injuries was classified as involving one region or neighbouring regions. Involvement of more than three regions, opposite regions or involvement of the whole scalp was summarized as other regional combinations. Except in the subdivisions pertinent to injuries involving only one region, the temporal and parietal regions were combined and simply denoted as lateral regions.

For every case the relation of the scalp injuries to the cranial fractures was analyzed and if possible subsequently matched in order to estimate the area of impact. If the fracture observed at the autopsy was linear it was estimated, based on earlier findings (25;29;30), that the corresponding impact had occurred anatomically nearby to the linear fracture. It was assumed that the linear fracture either reached the area of impact, crossed the area of impact or ended near the area of impact (25;29;30). All the other fracture types, except from the ring fractures, were characterized by local bone failure corresponding directly to the area of impact facilitating the matching. If the fracture anatomically was located only in the base, it was estimated, based on earlier findings (26) that a possible related impact could have occurred at base level or on the vault. It is well known that other impacts, e.g. facial impacts or fall on the buttocks, cause basilar fractures (24;123), but to minimise interpretational bias we chose to classify impacts which could not, with a reasonable amount of certainty, be related to fractures as "non relatable" (and this included facial injuries). Some cases were characterized by having several fractures apparently independent of each other, e.g. a longitudinally oriented linear fracture in the occipital bone and transversely oriented linear fractures in the petrous parts of both temporal bones. Gurdjian et al. (30) has shown that additional fractures can occur at a distance away from the impact. These cases were classified depending on whether a scalp injury could be associated directly to the presumed primary impact area and fracture. If this was not possible the cases were classified as inconclusive. In a few cases the fracture description in the autopsy reports was unclear and these cases were also classified as inconclusive.

Results

The majority of the individuals died due to accidents, primarily traffic accidents and falls (table 1). The cause of death was craniocerebral injuries in 55% of the cases and in nearly half of the remaining cases poly-trauma, i.e. the craniocerebral injuries were combined with substantial injuries of other organ systems. There was no difference in the cranial fracture characteristics of these two groups. In a few cases the cause of death was undetermined.

		Manner of death					Total
Trauma type		Accident	Homicide	Suicide	Natural	Unknown	n
Traffic	Car occupant Driver	75		4		1	80
	Car occupant Front seat passenger	13					13
	Car occupant Back seat passenger	10					10
	Pedestrian	53					53
	Bicycle riders	39					39
	Motorcycle riders	32					32
Other	Train	3		5			8
Other	Airplane	8					8
Other	Other traffic situations	9		1			10
	Subtotal						*253*
Falls/jumps from heights	Ground level	39	4		3	2	48
	2 - 3 metres	31				1	32
	3 - 5 metres	16					16
	> 5 metres	10		9			19
	No height known	13		1		1	15
	Subtotal						*130*
Hit/struck by blunt object and/or interpersonal violence	Hit/struck/compressed by blunt object	16	18				34
	Blows and kicks		4				4
	Subtotal						*38*
Other		5				2	7
Total		372	26	20	3	7	428

Table 1. Characteristics. The table shows the different trauma types, the distribution of individuals for each trauma type and the overall relation to the manner of death.

Fracture types

The fractures of the neurocranium varied from single, small fractures in the eye loft of the frontal bone (e.g. car driver involved in a frontal collision) to comminute fractures of the cranium (e.g. fall from a height of 5 metres). Table 2 shows the overall distribution of the fracture types and their anatomic localisation. The linear fractures comprised ~60% of the total material with varying orientations in the cranium: longitudinal; transverse; or oblique or a combination of these. The other fracture types ranged from involving small areas of the vault, e.g. a local depressed fracture, to involving large areas as in massive comminute fractures. Some of these fractures were combinations of the fracture groups (n=42), e.g. depressed fractures combined with multiple fractures or linear fractures, and were therefore grouped separately. The overall anatomical localisation of the fractures was the vault and base and secondly only the base, resulting in a basilar involvement in approximately 90% of all the cases. Sixteen of the transversely oriented linear fractures located in the base (16/45) were described as "hinge fractures" in the autopsy reports. Most of the linear vault fractures had extensions into the base and there were relatively few fractures involving only the vault. The linear fractures in the group of vault fractures were characterized by being orientated in different planes, e.g. horizontally in the vault; in a coronal plane involving the vertex; or following the sutures with diastases. In eleven cases we were not able to clearly classify the fracture type (inconclusive).

Table 2. The fracture types, their anatomical orientation and localisation. The table shows the fracture classification with the different fracture types and their anatomic localisation.

	Linear fractures			Other fracture types							
	l	t	o/c	Depressed	Multiple	Spider Web	Ring fracture	Comminute	Combination	Inconclusive	Total
Base and vault	27	53	31	15	17	1		54	31	5	234
Base	50	45	25	4	1	1	15	5	8	3	157
Vault	7	9	4	3	4	1		3	3	3	37
Total	84	107	60	22	22	3	15	62	42	11	428

l - longitudinal
t - transverse
o/c - oblique or combination

Scalp injuries

Almost all cases (398/428) presented one or more scalp injuries in the different regions of the scalp. The scalp injuries consisted of contusion wounds, excoriations, sugillations/subgaleal haematomas and other injuries (e.g. burns). The six regions comprised 722 single or groups of injuries (e.g., a sugillation with a central excoriation) (see table 3). Figure 2 shows how many injuries in each region were related to a cranial fracture.

External injuries associated to fractures	n
One region	181
Neighbouring regions	112
> 3 regions	10
Opposite regions	8
Whole scalp	32
No lesions	29
Non relatable	50
Other lesions	6
Total	428

Table 3. The regional classification and the number of external injuries. The table shows the classification of injuries and the number of injuries related to cranial fractures.

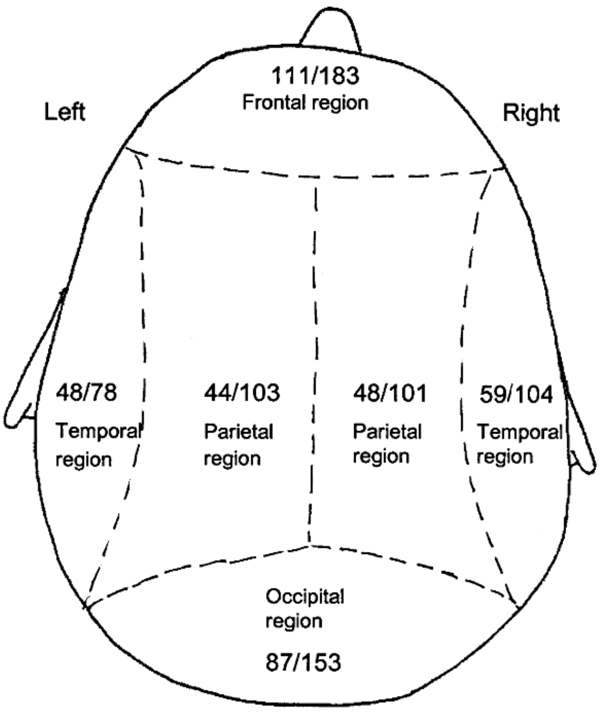


Figure 2. Distribution between the numbers of fracture related injuries and the total registered number of injuries in each classified region.

Impact and fracture type

Table 4 shows how the injuries involving one or more (neighbouring) regions are related to the cranial fracture types. In 50 cases the scalp injuries could not be associated with fractures, and in 29 cases scalp injuries had not been reported in the autopsy reports. (Eleven of these 29 cases had been hospitalized and treated prior to death, and six of these survived more than three days, which could have resulted in healing of minor scalp injuries prior to the autopsy.) The cases with no injuries or in which injuries were not relatable to the fractures, as well as the fractures classified inconclusive, were disregarded in the subsequent analysis.

The area in which an impact caused a fracture was estimated by relating the scalp injuries to the cranial fractures. In table 4 it is seen that the longitudinal linear fractures mainly were induced by impacts in the occipital and frontal region (53/69), while the transverse linear fractures were caused by fracture related impacts in the parietal, temporal and lateral regions (52/80), in some cases also in combination with the frontal or occipital region (16/52). The linear fractures oriented obliquely or in multiple directions were predominantly caused by fracture related impacts in the border area of regions, especially in the frontal or occipital area combined with the lateral regions (40/51). When impacts caused injuries extending beyond one region, i.e. into neighbouring regions, these injuries always included the lateral regions generally resulting in equally many other fracture types (48/108) and linear fractures (60/108), mostly oriented transverse (n=36) or oblique (n=19).

The other fracture types, except from the ring fractures, were characterized by being closely related to the impact area. Table 4 shows that the depressed fractures were typically located in the parietal, temporal and lateral and/or frontal regions (15/19), affecting mostly the temporal or parietal bones. The comminute fractures were caused in impacts involving one or neighbouring regions as well as in impacts which included several regions or impacts which were grouped as other regional combinations, e.g. severe scalp laceration, partial amputation of the head, severe burns etc. The 15 cases with ring fracture were all complete (except one) and could not be associated with a specific lesion pattern. In six of these cases no scalp injuries/impacts were found, while the remaining injuries were distributed evenly between the frontal, parietal, temporal and occipital region.

Table 4. The overall fracture types and their related impact regions. The table shows the relation between the different fracture types and the impact regions.

The table is subdivided into linear fracture types and the different other fracture types as well as the regional impact classification.

	Linear fractures				Other fracture types									
	l	t	o/c	sub total	Depressed	Multiple	Spider Web	Ring Fracture	Comminute	Combination	sub total	Subtotal Linear + Others	Inconclusive	Total
I. One region														
Frontal	*8*	*5*	*9*	22		*6*			*9*	*5*	20	42		*42*
Occipital	*45*	*1*	*14*	60	*2*	*2*	*1*	*3*	*2*	*5*	15	75	*2*	*77*
Parietal	*4*	*12*	*1*	17	*5*				*2*	*3*	10	27		*27*
Temporal	*2*	*22*	*3*	27	*3*	*1*			*1*	*3*	8	35		*35*
Subtotal	59	40	27	126	10	9	1	3	14	16	53	179	2	181
II. Neighbouring regions														
Lateral	*2*	*18*	*6*	26	*3*	*3*	*1*		*5*	*3*	15	41	*1*	*42*
Lateral + Frontal	*3*	*13*	*6*	22	*4*	*3*		*1*	*9*	*6*	23	45	*2*	*47*
Lateral + Occipital		*3*	*5*	8	*1*				*2*	*4*	7	15		*15*
Other combinations		*2*	*2*	4		*1*			*2*		3	7	*1*	*8*
Subtotal	5	36	19	60	8	7	1	1	18	13	48	108	4	112
III. Other regional combinations	5	4	5	14	1	4			26	8	39	53	3	56
Subtotal (I+II+III)	69	80	51	200	19	20	2	4	58	37	140	340	9	349
No lesions	*4*	*9*	*4*	17		*1*	*1*	*6*	*2*	*1*	12	28	*1*	*29*
Non relatable	*11*	*18*	*5*	34	*3*	*1*		*5*	*2*	*4*	16	49	*1*	*50*
Total	84	107	60	251	22	22	3	15	62	42	168	417	11	428

l - longitudinal; t - transverse; o/c - oblique or combination

Fractures, impacts and trauma type

The different trauma types were characterized by fracture related impacts in different regions and different fracture types. These data are presented in table 5 and 6. Table 5 shows the direct association between the linear fractures, their impact region and trauma type. Table 6 shows the same for the other fracture types. The cases with no injuries, not relatable injuries and inconclusive fractures as also the spider web fractures were not included in the tables.

Table 5 and 6 show that car drivers sustained linear and other fracture types in an equal number (n=24 and n=29 cases, respectively), and except in one case the impact area never included the occiput. Comminute fractures were the single most common fracture type for car drivers (16/52), in keeping with the high energy nature of many collisions, followed by transverse linear fractures (10/52), due to impacts in the parietal, temporal, lateral and/or frontal regions. Conversely, transverse linear fractures were not found in any of the front seat or back seat car occupants. Linear fractures were the most common fracture types for bicycle riders (23/33) and amongst these the most common were transverse fractures due to parietal, temporal, lateral and/or frontal impacts (9/23). One third of bicycle riders sustained other fracture types (table 6), e.g. one ring fracture, suggesting greater energy. There was no evident resemblance regarding the localisation of fracture related impacts in falls from a bicycle versus ground level or 2-3 metre falls. There was seldom information whether bicycle riders had used protective helmets. In the few cases were this was the case the lesion or fracture pattern did not differ from the unprotected group. Like the bicycle riders, the group of pedestrians (n=44) mainly sustained fracture related impacts in the parietal, temporal, lateral and/or frontal regions of the head (29/44). Occipital impacts in traffic accidents were mostly sustained by bicyclists (8/33) and pedestrians (9/44) inducing longitudinally oriented linear fractures in eleven of these cases. Overall, traffic accidents had a high proportion of comminute fractures (47/194). Not unexpectedly, this proportion was the highest for the traffic accident group denoted “Other” which mainly included train and aircraft accidents (11/21).

Table 5. Linear fractures, their orientation, their related impact regions and trauma types. The table shows the relation between the linear fractures, impact region and trauma type. The table is subdivided by trauma type, fracture orientation and the different regional impact classifications and their impact regions.

		Longitudinal												Transverse												Oblique or combination												Total
		One Region					Neighbouring R					Other		One Region					Neighbouring R					Other		One Region					Neighbouring R					Other		
	Trauma type	F	O	P	T	n	L	LF	LO	Ot	n		N	F	O	P	T	n	L	LF	LO	Ot	n		N	F	O	P	T	n	L	LF	LO	Ot	n		N	
Traffic	Car D	3	1			4						1	5	2		2	1	5	1	4			5	4	14	2				2	2				2	1	5	24
	Car F		2			2							2														1			1		1			1		2	4
	Car B																															1		1	2		2	2
	Cyclist		5			5	1				1		6		1	1	3	5	3	2			5		10		1	1	2	4	1	1			2	1	7	23
	Pedestrian		6			6						1	7	1		2	2	5	6	1		1	8		13						1		1		2	1	3	23
	Motorcyclist	1	2	1	1	5		1			1		6	1			2	3	2		1		3		6	3			1	4				1	1		5	17
	Other		1	1	1	3							3				2	2							2													5
	Subtotal	**4**	**17**	**2**	**2**	**25**	**1**	**1**			**2**		**27**	**4**	**1**	**5**	**10**	**20**	**12**	**7**	**1**	**1**	**21**	**4**	**41**	**5**	**2**	**1**	**3**	**11**	**4**	**3**	**1**	**2**	**10**	3	**24**	**98**
Falls	Groundlevel	2	15			17		2			2		19			1	5	6				1	1		7		4			4			2		2	1	7	33
	2-3 m		8			8	1				1		9			3	3	6		2	1		3		9		3			3		2			2	1	6	24
	3-5 m		2			2							2			1	2	3	1	1			2		5	2	1			3							3	10
	> 5 m	1	1			2							2				1	1	1				1		2	1				1							1	5
	No height known		2	1		3							3			1		1		1			1		2		1			1		1	2		3		4	9
	Subtotal	**3**	**28**	**1**		**32**	**1**	**2**			**3**		**35**			**6**	**11**	**17**	**2**	**4**	**1**	**1**	**8**		**25**	**3**	**9**			**12**		**3**	**4**		**7**	2	**21**	**81**
Accident	S/C	1				1							1	1			1	2	1	1			2		4		1			1							1	6
	Subtotal	1				1							1	1			1	2	1	1			2		4		1			1							1	6
Interpersonal violence	Hit blunt object											2	2						1	1	1		3		3						1				1		1	6
	B/K																		2				2		2						1				1		1	3
	Subtotal											2	**2**						**3**	**1**	**1**		**5**		**5**						**2**				**2**		**2**	**11**
Other				1		1						1	2			1		1							1	1	2			3							3	6
Total		**8**	**45**	**4**	**2**	**59**	**2**	**3**			**5**	5	**69**	**5**	**1**	**12**	**22**	**40**	**18**	**13**	**3**	2	**36**	**4**	**80**	**9**	**14**	**1**	**3**	**27**	**6**	**6**	**5**	**2**	**19**	5	**51**	**199**

Neighbouring R - neighbouring regions, Other - Other regional combinations
F - frontal, O - occipital, P - parietal, T - Temporal, L - lateral, LF - Lateral and Frontal, LO - Lateral and occipital, Ot - Other
Car D - Car driver, Car F - Car Front seat passenger, Car B - Car Back seat passenger, S/C - struck/compressed, B/K - blows/kicks

Table 6. Other fracture types, their related impact regions and trauma types. The table shows the relation between the different other fracture types, impact regions and trauma types. The table is subdivided by trauma type, the different regional impact classifications and the associated regions.

		depressed fracture												multiple fractures												Ring fracture												Comminut fracture												Combination												Total
		OR					NR					OC		OR					NR					OC		OR					NR					OC		OR					NR					OC		OR					NR					OC		
		F	O	P	T	**n**	L	LF	LO	Ot	**n**		**N**	F	O	P	T	**n**	L	LF	LO	Ot	**n**		**N**	F	O	P	T	**n**	L	LF	LO	Ot	**n**		**N**	F	O	P	T	**n**	L	LF	LO	Ot	**n**		**N**	F	O	P	T	**n**	L	LF	LO	Ot	**n**		**N**	
Traffic	Car D			1		**1**							**1**	2				**2**	1				**1**	**3**	**6**													3				**3**	1	2	1		**4**	9	**16**	2		1		**3**		1			**1**	1	**5**	28
	Car F			1		**1**		2			**2**		**3**																											1		**1**		1			**1**	2	**4**			1		**1**							**1**	8
	Car B													1				**1**		1			**1**		**2**																			2			**2**	1	**3**													5
	Cyclist											1	**1**	1				**1**							**1**		1			**1**							**1**	1				**1**			1	1	**2**		**3**				2	**2**		1	1		**2**		**4**	10
	Pedestrian						1				**1**		**1**						1	1		1	**3**		**3**		1			**1**		1			**1**		**2**		1		1	**2**	1	3		1	**5**	1	**8**	1	1	1		**3**		1			**1**	3	**7**	21
	Motor cyclist			1		**1**							**1**	1				**1**							**1**													3				**3**							**3**							1			**1**	2	**3**	8
	Other													1				**1**		1			**1**		**2**		1			**1**							**1**	2				**2**						9	**11**								1		**1**	1	**2**	16
	Subtotal			**3**		**3**	**1**	**2**			**3**	**1**	**7**	**6**				**6**	**2**	**3**		**1**	**6**	**3**	**15**		**3**			**3**		**1**			**1**		**4**	**9**	**1**	**1**	**1**	**12**	**2**	**8**	**2**	**2**	**14**	**22**	**48**	**3**	**1**	**3**	**2**	**9**		**4**	**2**		**6**	**7**	**22**	**96**
Falls/jumps from heights	Ground level						1				**1**		**1**						1				**1**		**1**																										1			**1**							**1**	3
	2-3 m							1			**1**		**1**											1	**1**																														1		1		**2**		**2**	4
	3-5 m																																															1	**1**		1			**1**		2			**2**		**3**	4
	> 5 m		1		1	**2**			1		**1**		**3**		1			**1**							**1**														1	1		**2**	1				**1**		**3**		1			**1**							**1**	8
	No height			1	1	**2**							**2**																														1				**1**		**1**		1			**1**							**1**	4
	Subtotal		**1**	**1**	**2**	**4**	**1**	**1**	**1**		**3**		**7**		**1**			**1**	**1**			**1**	**1**	1	**3**														**1**	**1**		**2**	**2**				**2**	1	**5**		**4**			**4**	**1**	**2**	**1**		**4**		**8**	**23**
Accident	S/C				1	**1**	1				**1**		**2**				1	**1**							**1**																							3	**3**				1	**1**							**1**	7
	Subtotal				**1**	**1**	**1**				**1**		**2**				**1**	**1**							**1**																							**3**	**3**				**1**	**1**							**1**	**7**
Interpersonal violence	Hit blunt object		1			**1**		1			**1**		**2**		1			**1**							**1**																		1	1			**2**		**2**	1				**1**	2		1		**3**	1	**5**	10
	B/K																																																	1				**1**							**1**	1
	Subtotal		**1**			**1**		**1**			**1**		**2**		**1**			**1**							**1**																		**1**	**1**			**2**		**2**	**2**				**2**	**2**		**1**		**3**	1	**6**	**11**
Other				1		**1**							**1**																																																	1
Total			**2**	**5**	**3**	**10**	**3**	**4**	**1**		**8**	**1**	**19**	**6**	**2**		**1**	**9**	**3**	**3**		**1**	**7**	4	**20**		**3**			**3**		**1**			**1**		**4**	**9**	**2**	**2**	**1**	**14**	**5**	**9**	**2**	**2**	**18**	26	**58**	**5**	**5**	**3**	**3**	**16**	**3**	**6**	**4**		**13**	8	**37**	**138**

OR - one region; NR - neighbouring regions, OC - Other regional combinations
F - frontal, O - occipital, P - parietal, T - Temporal, L - lateral, LF - Lateral and Frontal, LO - Lateral and occipital, Ot - Other
Car D - Car driver, Car F - Car Front seat passenger, Car B - Car Back seat passenger, S/C - struck/compressed, B/K - blows/kicks

Cranial fractures due to falls presented a very characteristic impact and fracture pattern in that the occipital region, at times in combination with the lateral region, was involved in 49% (51/104) of these cases. This was most apparent in the subgroup of ground level falls (22/36) and falls from 2-3 metres (13/28). Table 5 shows that fracture related impact in the occipital and frontal region in ground level falls induced longitudinally oriented linear fractures in 89% (17/19) of the cases. Not surprisingly, an increase in the fall height seemed to cause a decrease in the linear fractures. Linear fractures comprised almost 92% (33/36) of all fractures in ground level falls, and this was reduced to approximately 38% (5/13) in falls from above 5 metres. With an increasing fall height, a more general involvement of the lateral region occurred more often. In contrast to the traffic accidents, only 5% (5/104) sustained comminute fractures. In three ground level falls the victim struck an object on the floor which caused the other fracture types (3/23). In 21 cases contre-coup fractures in the eye loft were registered at the autopsy, associated with impact in the occipital region (data not shown).

Accidents with blunt objects (n=13) happened in various settings and with various objects. The fracture related impacts (n=13) (see table 5 and 6) were located in the parietal, temporal, lateral and/or frontal regions (9/13) inducing mainly linear transverse fractures (n=4) and other fracture types (n=4). There were two depressed fractures.

The homicides (n=26) constituted four falls which happened in the course of a struggle, four assaults with blows, kicks or trampling on the victims head and eighteen assaults with a variety of different blunt objects. All of the fall cases sustained fracture related impacts in the occipital region with longitudinally oriented linear fractures (data not specified). In the remaining cases with fracture related impacts (n=20) (table 5 and 6) the lateral and/or the frontal or occipital regions were involved in 70% (14/20) of the cases. Also fracture related impacts in "other regional combinations" were common (30%, n=6/20), e.g. injuries in both parietal, one temporal and the occipital region. Involvement of only one region did not occur often (4/20). The other fracture types constituted more than half of the fractures (11/20) suggesting that both a substantial amount of force was used in these homicide cases and/or repeated impacts towards the same area.

Overall, regardless of trauma types, our study clearly shows some general trends regarding an association between occipital impacts and longitudinal linear fractures (45/69; 65% CI 53%-76%)

and lateral (temporal, parietal, or both) impacts and transverse linear fractures (52/80; 65% CI 54%-75%). Furthermore, we note that regarding depressed fractures these were most often caused by lateral impacts (15/19, 78% CI 54%-94%). More diffuse patterns were evidenced by linear fractures with an oblique orientation, and not surprisingly for comminute fractures, where impacts mostly were classified as "other combinations" (21/47, 45% CI 31%-59%).

Discussion

The main focus of this retrospective study was to explore the relation between impacts to the cranium and subsequent cranial fractures for different types of trauma. Central to this was the estimation of the area of impact based upon the association between the cranial fracture type and the external injuries as observed at autopsy. Realizing the complicated biomechanical process leading from an impact to a cranial fracture, we performed this estimation conservatively, so that any cases where the recording of either injuries or fractures was uncertain or seemed ambiguous were excluded. In 10% of our cases we were not able to relate the registered injuries to the fractures.

When we reviewed the cases, we also noted that scalp injuries had not been found in several cases, and this did not seem to depend on the energy level of the trauma or the associated fracture severity, e.g. comminute fractures in severe high energy traffic traumas or linear fractures in ground level falls on a tile floor. There could be various reasons for injuries not being present or not being recorded at autopsy: minute injuries not registered in the autopsy report; injuries overlooked by the pathologist if vital reaction was missing; preventive measures in the car interior (airbags) or various other trauma mechanisms than direct impact, e.g. hyperextension. The latter could also be true for the cases where we were not able to relate injuries with fractures. The lack of or minuteness of scalp injuries combined with severe cranial fracture or injuries of the central nervous system has been described earlier (27;32;54;120). Also Kremer et al. (116) found that over half of the included fall cases did not sustain lacerations, in a retrospective study systematically analysing the relation of skull fractures to the Hat Brim Line. However, in their study there was no mention of other external injuries. Nonetheless other studies have shown that scalp injuries are more often associated with severe head injury or cranial fracture than not (58;114). In our study there were 10 cases with only facial injuries, which were classified as not being directly associated to the fractures, but it is possible that the facial impacts may have resulted in basilar fractures, as this is a well known trauma mechanism (26;56;120;123). In a future study it may be of interest to investigate trauma mechanisms with indirect forces to the head more closely.

Our results, concerning the cases in which an association between scalp injuries as regards impact and subsequent cranial fracture could be made, confirmed earlier findings (26;28-30). The fracture related impacts in the lateral regions resulted mainly in transverse linear fractures, impacts in frontal and occipital regions resulted mainly in longitudinal fractures and impacts in the lateral parts of a single region resulted mainly in oblique fractures, which has also been found by others (26;29;30). However, exceptions to these generalizations exist, especially regarding basilar fractures only, which is indicated by both our results and the results of others (124). Gurdjian et al.(30) demonstrated that linear fractures are caused by impacts on broad, flat surfaces. This was probably also the case for the origin of the linear fractures in our material. The other fracture types were closely related to impacts and were, except from the ring fractures, characterized by failure of the bone in relation to the impact. Gurdjian et al. (30) showed that failure of the bone is the result of impacts with a high enough energy and/or velocity level, e.g. either in a small area resulting in a depressed fracture, or in a larger area resulting in a multiple or comminute fracture. It is also known that very little additional force is needed to induce severe fractures with local bone failure in an already (linearly) fractured cranium (30;125).The ring fractures in our material were, except from one ground level fall, caused in traffic and in our material the localisation of the scalp injuries varied. In 70% of these cases impact injuries were either not found or could not be related directly. This may support the assumption of indirect force e.g. hyperextension as ring fractures are often associated with high energy traumas (118;119) and are caused by various trauma mechanisms (24;118).

We found that the fracture related impact in linear fractures with involvement of both base and vault often was sustained in the vault, resulting in a linear fracture extending into the base, which also has been noted by others (28;30;94). The orientation of the linear fractures in the base and vault mainly corresponded to the weak and strong areas of the cranium confirming earlier findings (26;30). Fractures located only in the vault occurred only in a few cases, which was in concordance with Vance (28). This is probably also a reflection of the selection of our material: namely that all our cases sustained fatal injuries. Presumably a clinical study would comprise more vault fractures. The other fracture types were, except from comminute and ring fractures, often the result of a trauma in a rather limited area with subsequent failure of the bone and were therefore mostly located in the base and/or vault.

The linear and the other fracture types were distributed 3:2 in our material. In other studies (21;93;126) the share of linear fractures was largely the same. In our material the fracture related impacts involving only one region produced linear fractures in two thirds of the cases. As soon as the impacts involved several regions the opposite was the case, as other fracture types were produced in two thirds of the cases. This suggests a higher velocity and/or energy level in these cases possibly combined with a biomechanically complicated sequence of impacts to the head. Falls resulted in 70% of the fracture related impacts in one region while traffic traumas resulted in 40% of these. More than half (60%) of the fracture related impacts in several or neighbouring regions were caused in traffic traumas while only 30% were caused in falls. Individuals hit or struck by blunt objects in the group of homicides, mostly (80%) sustained fracture related impacts involving neighbouring or several regions classified as "other regional combinations". Also the share of "other fracture types" was high. Both the energy and velocity in these types of trauma is not as high as in e.g. traffic accidents, but the amount of scalp injuries and severe fracture types caused per case in homicides by blunt object was higher than in the other trauma types. This may suggest that the homicide cases often receive several blows resulting in severe fractures.

In keeping with the findings of others (34;58) we found that car occupants mainly sustained fracture related impacts in the frontal and lateral regions inducing slightly more other fracture types than linear indicating a high energy and velocity level in these traumas. Cyclists and pedestrians in our material sustained equally many other fracture types and linear fractures (oriented longitudinally and transversely) resulting from fracture related impacts in the lateral and occipital regions. Similar results regarding pedestrians and bicyclists were found by others (38;42).

In ground level falls we found the largest amount of mainly linear fractures oriented longitudinally caused by fracture related occipital impacts; the other fracture types in this height were scarce. Others (51;52;54) also found that the most common impact region was the occiput followed by the lateral regions (52) or frontal region in ground level falls (54) as well as in falls down stairs (52). The share of other fracture types rose as soon as the height was over 3 metres with impacts more often involving several regions and a decrease of occipital impacts. Cummins et al. (50) found a marked involvement of impacts in the frontal region with increasing height, which did not seem to be the case in our study. The increased impacts in several regions in heights over 3 metres might be explained by increased movement of the body during the fall and prior to impact (127). Contre-coup fractures were found in 16% of the falls which is similar to other studies (128;129). Further studies are needed to establish the frequency and pathology of contre-coup fractures in falls.

The accidents with a blunt object resulted in nearly equally many other fracture types and linear fractures, typically transversely oriented. In the accidents the impact regions were mostly the lateral regions followed by the frontal regions. In the homicides the frontal or occipital region was only involved in a few cases, mainly in combination with other regions, suggesting that homicidal blunt force to the head is aimed mostly towards the lateral regions of the head. We noted that the external injuries often involved several regions, i.e. there were several external injuries over a large area. Kremer et al.(116) found similar results with a higher number of lacerations in blows compared to falls. They also found a predominance of cranial fractures located on the right side in falls and on the left side in homicides. In our study a side lateralization was not noted. In a clinical study about interpersonal violence Brink et al. (100) report that injuries mostly occur in the face, the lateral sides of the head and more seldom in the occiput. However, it must be assumed that the injury pattern in a homicide differs from assaults without homicidal intentions, but it seems plausible that mainly the lateral sides or the occiput are exposed in homicides, e.g. when the victim is lying down. Also in both in homicides and accidents it is possible that the victim turns the lateral side of the head towards the causative object.

The biomechanical process from an impact leading to a cranial fracture is complicated and various factors (e.g. velocity of object/individual; mass; impact area and surface) have to be considered in order to evaluate the sustained external, cranial and also intracranial injuries. Our study has basically validated earlier studies, especially the seminal studies by Rawling and Gurdjian et al. (26;29;30), regarding the associations between impact area and subsequent cranial fracture. In our study we further analysed this by adding the trauma type as a parameter. As such, our data reflect the spectrum of cranial fractures in modern forensic autopsy material. Our study may thus also point to some difficulties in terms of interpreting autopsy findings in these cases. For example, although we were able to relate scalp injuries to cranial fractures in most of our cases (90%), we also made note of the fact that there often were many more scalp injuries per case; indeed we initially found that approximately 48% of all scalp injuries could not be directly related to any cranial fractures. Probably most external injuries are associated with circumstances connected with the trauma type, but it does mean that when cranial fractures are present there must be a thorough observation and registration of all external injuries, and estimation of impacts must be carried out by carefully comparing the injuries with the fracture pattern. A prediction of which impacts may have caused a fracture is thus almost impossible based solely on an external examination.

Furthermore, our results show a very common involvement of the cranial base. This may have implications for the use of CT-scanning as a diagnostic tool in forensic pathology, as earlier studies (1;130) have shown that the CT scan based diagnosis of fractures in the cranial base may be difficult. In a previous study (131), we found that various CT visualisation protocols may alleviate this problem, but that differentiation between, e.g. a fall on the back of the head or a blow to the back of the head, is difficult and still necessitates an autopsy, combined with such basic knowledge about impacts, cranial fractures and trauma types as presented here.

Paper III - Craniocerebral Trauma - Congruence between Post-mortem Computed Tomography Diagnoses and Autopsy Results - A 2-year retrospective study

Materials and Methods

Our study is based upon medico-legal autopsies performed at our institute in the years 2003 and 2004. In this period 1621 autopsies were performed, with 578 bodies being CT-scanned prior to autopsy in 2003 (70.1%), and 380 (47.6%) in 2004, respectively. The scan-operator was a physician with approximately 13 years of experience in forensic pathology. The CT-scans were routinely performed immediately after the medico-legal external examination and the scan-operator did not receive any information about the circumstances regarding the deaths. The CT-scan based diagnoses thus reflected the routine workflow conditions.

A total of 56 cases were included (2003: 39; 2004: 17) comprising 43 males and 13 females, with an age-range from newborn to 85 years (mean age: 39.2 years). The cases were selected by manually sorting the autopsy-reports for cases with an autopsy diagnosis of fracture of the neurocranium and a performed CT-scan prior to the autopsy. Cases with fractures of the viscerocranium only or the cervical column were not included. The 56 cases comprised homicides, suicides and accidents (manner of death), involving blunt and sharp trauma, gunshot, falls and traffic accidents (cause of death) (see Table 1). The material was generally characterized by severe head injuries, and in the autopsy reports 20 of the 56 cases were diagnosed with a crushed cranium.

Manner of death Cause of death	Homicide	Suicide	Accidents	Total
Blunt trauma *-Traffic-accident* *-Fall* *-other*	3	4	38 *27* *10* *1*	45 *27* *10* *1*
Sharp trauma	1	0	0	1
Gunshot	6	4	0	10
Total	10	8	38	56

Table 1. Manner and cause of death

The CT-scans were obtained by a Spiral Siemens Somatom Plus 4. Two standard protocols for head scans were used during the period: 27 cases were scanned with 8 mm slices and pitch 1 ("protocol A") and 28 cases were scanned with 3 mm slices and pitch 1.5 ("protocol B"). The protocols had been established with the consultancy of a radiographic technician. Only very few of the cases were scanned with both protocols. In one case there was no information about the used scan protocol. The use of two protocols was during the period dependent on the expected injuries and was thus a compromise between cost, effectiveness, resources and time-consumption in the daily routine work.

The autopsy reports and the CT-scan reports were compared regarding the diagnosis of cranial fractures. The diagnoses based upon the CT-scans were made by the scan operator. It was not possible to re-evaluate the CT-scans for this study. As a first approximation we assessed whether the diagnosed fractures comprised only the cranial vault, or the cranial base, or both, as diagnosed on CT-scan and at autopsy, and cross-tabulated the results dependent on the usage of scan-protocol. The data are presented raw in order to reflect the routine work conditions genuinely. We then subdivided the fractures according to whether they affected the anterior, medial and posterior fossae and cross-tabulated the results in the same fashion. Finally, the diagnostic frequencies of the fractured cranial bones were compared. We also registered whether brain injuries had been observed macroscopically at the autopsy and on the CT-scan. Histological analysis of brain injuries found macroscopically is not performed routinely at our institute and was also not performed in the included cases.

Results

Congruence of the CT-scan based fracture diagnoses with the autopsy diagnoses

A simple cross-tabulation between the fracture diagnoses made by CT-scan according to the used protocol and at autopsy, focusing only on whether the fracture involved the cranial vault and base, is seen in Table 2. The fracture diagnoses were equivalent in 34 cases, i.e. in 34/56 cases fractures diagnosed during autopsy had been diagnosed in the same location as on CT-scan. Fractures were not diagnosed at all on CT-scan in 13 cases, and the full extent of combined vault and base fractures was not realized on CT-scan in 9 cases. The fractures involving only the vault (n=3) were missed, while approximately half of the fractures involving only the cranial base (n=6) were missed.

Autopsy / CT-scan (A/B protocol)	Vault and base	Vault	Base	Total
Vault and base	27 (11/15)*	0	0	27 (11/15)
Vault	2 (2/0)	0	0	2 (2/0)
Base	7 (3/4)	0	7 (1/6)	14 (4/10)
No fracture	4 (4/0)	3 (2/1)	6 (4/2)	13 (10/3)
Total	40 (20/19)	3 (2/1)	13 (5/8)	56 (27/28)

* In one case there was no information about whether scan-protocol A or B was used

Table 2. Cross-tabulation between a correct diagnosis regarding fractures involving the anatomic entities cranial base and/or vault sorted into groups according to the used scan protocol. The data are presented raw.

Twenty of the 27 cases involving fracture of the cranial vault and base were cases with total crushing of the cranium, which was easily evident upon CT-scanning regardless of the scan protocol used (Figure 1). In thirteen cases fractures were missed on the CT-scan. The missed fractures localized in only the cranial vault (n=3) and both the cranial base and vault (n=4) were described as fissures in the autopsy-reports, which could explain why these fracture-systems were missed on the CT-scan. Scan protocol A had been used in 10 of the 13 cases were no fracture had been diagnosed at all.

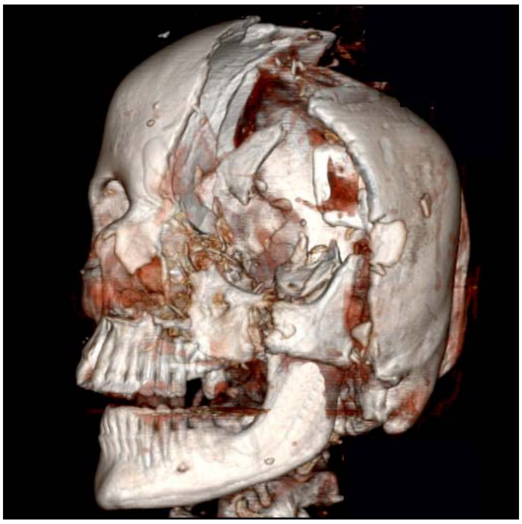


Figure 1. 3-dimensional reconstruction of a skull diagnosed as crushed at the autopsy and on the CT-scan

Table 3 shows the congruence between autopsy and CT-scan according to the used scan protocol regarding fractures of the cranial fossae. Diagnosing fractures involving the anterior and posterior fossae by CT-scan was more difficult than identifying fractures involving the medial or posterior fossae, apparently regardless of whether protocol A or B was used. Regarding the medial fossa however, there was a marked difference. The use of protocol B seemed to greatly facilitate diagnosing the fractures.

Anatomic Localization	Autopsy	CT-scanning Usage of protocol A/B	Congruence CT-scanning (Protocol A/B)		No congruence CT-scanning (Protocol A/B)
Fossa anterior	20	10/10	4 (3/1)	20%	16 (7/9)
Fossa medialis	29	15/14	15 (4/11)	51,7%	14 (11/3)
Fossa posterior	15	9/6	9 (5/4)	60%	6 (4/2)
Total	64	34/30	28 (12/16)	43,8%	36 (22/14)

Table 3. Congruence between autopsy and CT-scan according to used scan protocol regarding fracture of the cranial base. The total is higher than 56 cases due to involvement of several fossae in one case.

Table 4 shows the cranial bones in which fractures were diagnosed on CT-scan versus by autopsy.

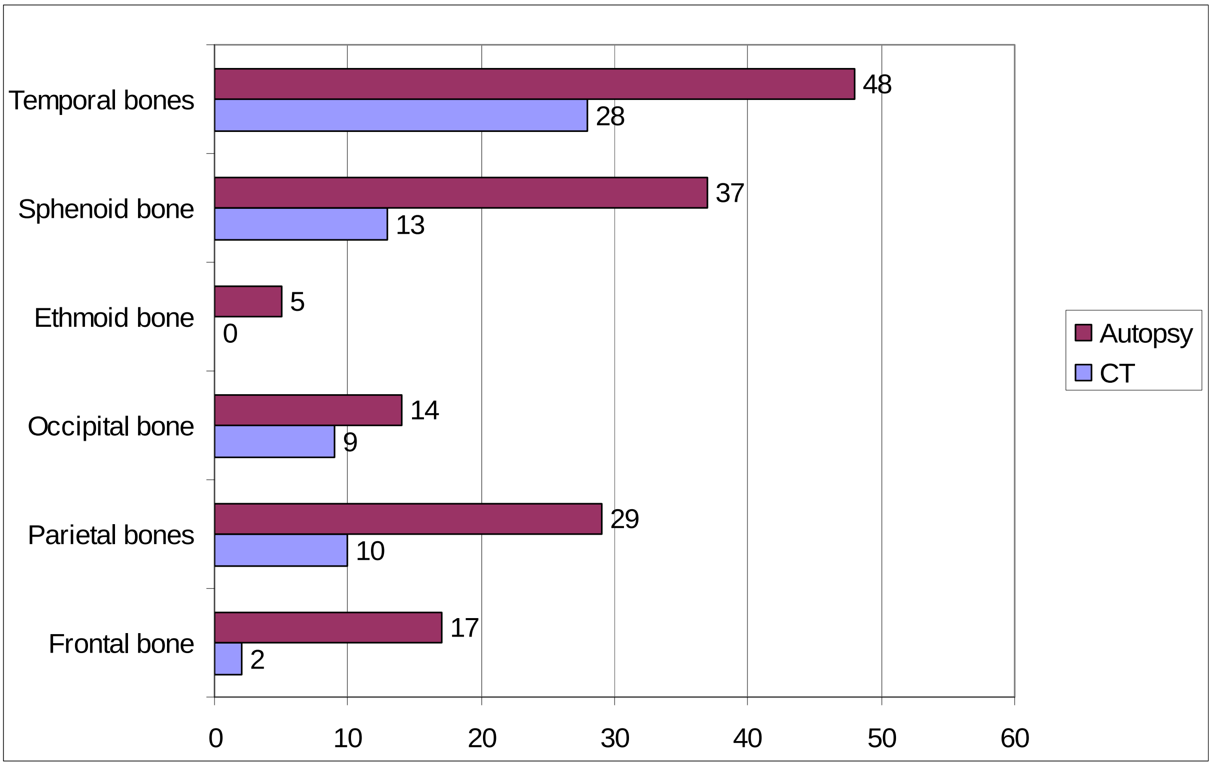


Table 4. Case-based congruence between CT-scan diagnosis and autopsy diagnosis of fractures

Most cases often involved several bones. The temporal and sphenoid bones of the cranium were frequently involved both unilaterally and bilaterally, which is consistent with the high number of fractures in the anterior and medial fossae. Approximately half (54%) of the bilateral fractures of the temporal bones were diagnosed, while the unilateral fractures not were diagnosed frequently (12%). The same pattern was seen for the parietal bone, as bilateral fractures were more often diagnosed correctly on CT-scan than the unilateral fractures (42.8% and 26%, respectively). The fractures were diagnosed as unilateral on CT-scan in 6 cases of the bilateral temporal bone fractures and in one case of the bilateral parietal bone fracture. The unilateral and bilateral fractures of the sphenoid bones were diagnosed correctly in approximately half of the cases (40% and 50%), but only in less than a quarter when concerning the frontal bone (23, 5%). Furthermore, none of the three fractures of the ethmoid bone were diagnosed on CT-scan. Fractures in the occipital bone were diagnosed in 72% of the cases (Fig. 2 and 3). Nine of the 12 cases which on the CT images were diagnosed with bilateral temporal fractures were scanned with protocol B, as were 5 of the 6 cases diagnosed with bilateral sphenoid fractures. Apart from this no diagnostic difference between the uses of scan protocol A or B was noted.

Figure 2. Axial CT image of the cranial base of a man who fell down a stair case. The point of impact with a contusion wound was in the occiput. The figure shows the fracture in the occipital bone as it was seen on CT images.

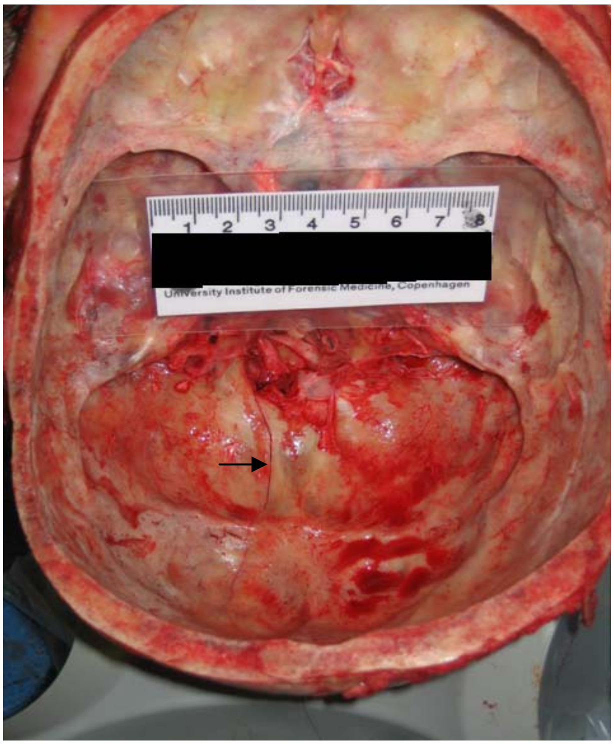


Figure 3. Image of the same cranial base as in figure 2 as it was seen at the autopsy.

Congruence of the CT-scan based brain injury diagnoses and autopsy diagnoses

There was generally equivalence regarding the diagnoses of brain injuries based upon CT-scan and autopsy (Table 5a-b). Often several types of injuries were seen in each case. The cases with subarachnoid and subdural hemorrhages were diagnosed relatively often (62.5% and 69.2%, respectively). This is also reflected in the measurement of inter-observer agreement which is substantial for both subarachnoid (κ=0.622) and subdural hemorrhage (κ=0.728) but poor for epidural hematoma (κ=0). We checked the description of the subarachnoid hemorrhages in the autopsy-reports of the cases where the hemorrhage had not been diagnosed on CT scan. There was no consistent pattern as the subarachnoid hemorrhages varied in severity and location. The dimensions of the subdural hemorrhages were, except from one case, not described in the autopsy-reports. The diagnostic frequency in this material did not differ whether scan-protocol A or B was used. Interestingly, there were a few cases of CT-scan based diagnoses of subarachnoid hemorrhage (n=2), subdural hematoma (n=1) and epidural hematoma (n=1), which were not diagnosed at the autopsy.

Autopsy / CT scan		Subarachnoid hemorrhage		Subdural hematoma		Epidural hematoma	
		+	-	+	-	+	-
Subarachnoid hemorrhage	+	10	2				
	-	6	38				
Subdural hematoma	+			9	1		
	-			4	42		
Epidural Hematoma	+					0	1
	-					0	55

Table 5a. Distribution regarding the diagnoses of extra-axial hemorrhage by autopsy and CT scan.
The κ-coefficients are presented for each diagnosis: Subarachnoid hemorrhage κ=0.622; Subdural hematoma κ=0.728; Epidural hematoma κ=0

The diagnostic frequency of cerebral injuries (contusions, lacerations, edema and incarceration) varied somewhat. Contusions were diagnosed on CT scan but not at autopsy in 13 cases and this inconsistency is reflected by the inter-observer agreement which is slight (κ=0.181). Lacerations were diagnosed relatively often on CT-scan (79.2%, κ=0.727 substantial agreement), while only half of the cases with edema were diagnosed and the inter-observer agreement was moderate (κ=0.515). None of the cases with incarceration were diagnosed on CT-scan (κ=0). Overall, the diagnostic frequency of these lesions did not seem to differ dependent on the scan protocol.

Autopsy / CT scan		Brain contusion		Brain laceration		Brain edema		Incarceration	
		+	-	+	-	+	-	+	-
Brain Contusion	+	23	13						
	-	9	11						
Brain laceration	+			19	2				
	-			5	26				
Brain edema	+					5	3		
	-					4	44		
Incarceration	+							0	0
	-							5	51

Table 5b. Distribution of diagnoses regarding cerebral lesions by autopsy and CT scan
The κ-coefficients are presented for each diagnosis: Brain contusion κ= 0.181; Brain laceration κ=0.727; Brain edema κ=0.515; Incarceration κ=0

Discussion

Diagnostic CT-scanning of bodies prior to forensic autopsies has become increasingly used in forensic pathology. Several studies have analyzed the advantages of CT imaging for forensic purposes, performed both peri-mortem (69;70) and post-mortem (66-68;71-73), with differing results. Several studies have analyzed different forensic issues in a problem-based manner to exemplify the advantages and possibilities of forensic radiology (66;72;75-78). However, the actual settings in which CT and MR imaging is to be incorporated in the daily routine of most forensic institutes remain to be established. Undoubtedly, the implementation of these modalities is a question of both scarcity of research regarding their application in forensic pathology, as well as an appraisal of the resources, costs and effectiveness entailed by these techniques (20). Post-mortem CT imaging has been a routine at the institute in Copenhagen since 2002 (20), and in our experience the balance between CT-scanning for routine or research needs to be addressed. One obvious way of assessing the implementation of CT-scanning in forensic pathological practice is to analyze if diagnostic capabilities are improved.

Our results are based on material from a period when CT-scanning at our institute had just been established. Two head CT-scan protocols, A and B, were used routinely. Limitations of this study were its retrospective nature and the exclusive use of only one of the scan-protocols in a problem based manner in the daily routine work which made a comparison between the two protocols difficult. Therefore apart from inter-observer agreement (κ-coefficients) no statistical analyses were performed and the results therefore only reflect tendencies.

The results show that CT scan based diagnosis of fracture of the neurocranium is straightforward in large fracture-systems. These fracture-systems, with splintering of several bones, are often altered during the autopsy and reconstruction can be difficult. The CT images and 3-dimensional reconstructions may provide an excellent, preliminary overview of the fracture-system for the forensic pathologist prior to the autopsy, and may illustrate the fracture-system for non-medical professions, e.g. in court presentations or case reconstructions (66-68;72;92). However, our results show that the diagnosis of fractures in the anterior and medial cranial fossae based on CT-scan was difficult. Especially in cases with fissures the diagnostic frequency was low. This is also exemplified by the low CT-scan based diagnostic frequency of fractured bones related to the anterior fossae (ethmoid, frontal and temporals) and medial fossae (temporals and sphenoids).

Approximately half of the cases were scanned with the high resolution protocol B, which seemed to facilitate diagnoses of fractures in the medial fossae but apparently had no effect on the diagnostic frequency of fractures in the anterior fossae. This is also the case in clinical settings where the detection of fractures in these anatomic regions is a difficult task and requires thorough examination (1;130). For paired bones it was evident that the diagnostic frequency was higher as soon as the fractures involved both bones. The bilateral involvement of paired bones is most probably due to the cranium being subjected to a greater force resulting in more extensive fractures with dislocation or gaping which is easily diagnosed on CT-scan. Using a scan protocol with a higher resolution seemed to heighten the diagnostic agreement regarding bilateral fractures located in the medial fossae, although it did not seem to differ regarding unilateral fractures. In a forensic pathology setting the diagnosis of the whole fracture-system is important since it may provide clues of possible impact-points and thereby a possible causation (29). In this regard the diagnoses of fractures in the anterior or medial fossae is essential since they may provide information about the causative mechanism, e.g. a fall or a blow to the head (129), especially when cerebral lesions are missing.

Our results concerning the CT-scan based diagnoses of intracranial lesions were congruent with other studies, which noted that lesions smaller than the used slice thickness were missed on CT images due to limited resolution (67;72). We found a substantial agreement between CT and autopsy regarding subarachnoid hemorrhage, subdural hemorrhage and cerebral lacerations. The agreement between CT and autopsy regarding contusions was only slight and it is noteworthy that we found a higher frequency of contusions based on CT-scanning than at autopsy. It is possible that the small contusions were overlooked at the autopsy. Histological analyses and further studies are needed to examine this discrepancy further. The same holds true for the diagnoses of cerebral edema, which often is a macroscopic, observer-dependent diagnosis at the autopsy, which is difficult to diagnose (132) These results might suggest that the autopsy is not necessarily the golden standard regarding certain lesions, as it has been suggested by Yen et al. (72). In the clinical setting CT is the method of choice for the imaging of acute head-trauma, since it demonstrates lesions of the scalp, bone, brain membranes and cerebral lesions well (79;133). MRI is also increasingly being used in the forensic pathology setting (72). It is considered to be superior to CT for detecting suspected parenchymal pathologic changes or for the monitoring of parenchymal lesions especially in the posttraumatic phase (79;133). Yen et al. found that cerebral contusions and hemorrhages were visualized equally or slightly better on CT than MRI (72). Since much of the forensic post-mortem imaging is performed on traumatic and often instant deaths, CT would seem to be the method of choice. In cases where death occurs some time after the trauma or where a possible dating of traumatic lesions is important, MR imaging may be more useful. It has for example been reported that hemosiderin deposition can be visualized on MR images for many months after a hemorrhage (134).

Overall our results also reflect the circumstances of how routine post-mortem CT-scanning was implemented at our institute. If CT-scanning had been performed without the limitations imposed by the routine work procedures the diagnostic frequency might possibly have been higher. CT-scanning was performed in order to supplement the autopsy and demonstrate the possible cranial and cerebral injuries prior to the autopsy. However, it may be argued that a more satisfactory use of CT would be to select the most appropriate scan protocol depending on which lesions might be expected. This means that the scan-operator must have knowledge of the circumstances of death prior to CT-scanning. For example, in a case where possible differentiation between a blow to the head and a fall is needed, the routine protocol should be altered in order to enhance the visualization of the cranial base. Adjusting protocols in a problem-based manner demands a technically well-founded scan-operator which today is not necessarily implicit in a post-mortem scan setting. Therefore, when performing post-mortem CT-scanning in general, a decision has to be made whether the scans are supposed to generate material for research, routine-work or both and which specific posed forensic problem CT or MR scans have to solve or aid solving.

The CT scan images in this study were not diagnosed by a radiologist but by a forensic pathologist who during the time period in question CT-scanned approximately 950 bodies. When CT-scanning was introduced at our institute, the assumption was that post-mortem CT scans produced images which might be foreign for the clinical radiologist, especially concerning the expected lesions and their interpretation in a forensic context. For example, it had been experienced that morphological changes caused by cadaverosis, livores and gas-formation had made the interpretation of post-mortem CT-scans by a radiologist with no pathological experience difficult (K. Poulsen, personal communication). In both peri- and post-mortem studies which made use of a clinical radiologist the need of forensic training is stressed (72). Forensic radiology is a field between radiology and forensic pathology and regardless of which specialty forms the basis the need for either radiologic or forensic training is obvious and necessary. Given this, and to ensure that CT (and MR) is implemented in a competent and advantageous fashion in a forensic setting, it becomes paramount that the CT-scanning reports and autopsy reports are standardized (72). This ensures diagnostic uniformity, and allows for a more straightforward evaluation of diagnostic agreement and observer variation (both at autopsy and at CT-scanning). The autopsy reports are to date the golden standard in most settings, but we found that, e.g., cerebral contusions were often diagnosed at CT-scanning but where not mentioned in the autopsy-reports. This general problem has also been noted in other studies (67;72) and a possible solution for a standardized database has been suggested (135).

The evolving technology has for some years now improved CT-scanning procedures by decreasing scan-time and making faster image acquisition possible. While certainly not at this point being a substitute for a full autopsy, CT-scanning is an important addition to the forensic pathological "tool-box". We find that the diagnostic precision still needs to be improved. On the other hand, the capability for 3-D visualisation for complex cranial fracture systems and the ability to possibly diagnose cerebral lesions which are not evident at autopsy are real advantages. Finally, the digital nature of CT- or MR-images may make use of autopsy data in new ways, e.g., biomechanical analyses. This will open future possibilities for investigating, and reconstructing, injury patterns.

Paper IV- A comparative study of cranial, blunt trauma fractures as seen at medico-legal autopsy and by Computed Tomography

Methods

The study included fourteen cases (13 male, 1 female; age-range: 19-82 years, mean 47 years) with neurocranial fractures with a limited extension, caused by blunt violence. Nearly all of the cases were accidents (7 falls, 5 traffic-accidents) while one was the result of an assault with a baseball bat. In one case the manner of death was unknown.

Each body was scanned using a MSCT-scanner (Siemens Somatom Plus 4 Volume Zoom) prior to the autopsy. The scan was obtained in an axial plane using a slice collimation of 4 x 1 mm, pitch 0.65, 120 KV, mAs ~150 and bone algorithm (H60s).

At the autopsy, the cranium and the fractures were photographed and registered on a schematic drawing. Also, the fracture characteristics, extension and anatomic location were registered. For comparative purposes the neurocranium was divided into the following major anatomic regions: the vault (squamous part of the frontal bone, the parietal bones, the squamous part of the temporal bone) and the cranial base. The cranial base was further subdivided into the posterior fossa (occipital bone), the medial fossa (petrous part of the temporal bone, greater wing of the sphenoid, sella turcica) and the anterior fossa (orbital part of the frontal bone and the lesser wings of the sphenoid).

Two CT readings were performed. The first diagnostic fracture reading was performed by a forensic pathologist (CJ) on the Siemens scanner workstation. The axial images and a Multiplanar reconstruction (MPR) of the sagittal and coronal image planes with reconstruction increment of 0.5 mm were used. The second diagnostic reading of the same CT images was performed in cooperation with a board certified radiologist (BHB) on a Agfa Impax DS 3000 workstation. In addition to the MPR, a thick (5 mm) MIP was performed, and in selected cases a curved MPR. Due to technical difficulties one case did not undergo a second evaluation. Discontinuity or dislocation of the bone was defined as being a fracture. In some cases there was suture diastasis and to avoid interpreting these as fractures the width of the suture was compared to the parallel sutures.

Intracranial air or blood in the sinuses served as an indicator for possible fractures, but if a discontinuity of the bone was not visible the likely associated fracture was not registered.

In order to compare the extension and anatomic localisation of the fractures, the fracture diagnosis of the first and second CT scan evaluation were registered on the schematic drawings from the autopsy. It was also noted whether the fractures were uni- or bilateral and, on the CT scans, whether there was fluid in the sinuses or mastoids. This clearly showed whether congruence between the autopsy and the reconstructed CT images (MPR, MIP and curved MPR) existed. The data were analyzed regarding the recognition of an overall fracture system, providing important information about the traumatology in forensic casework, and whether the overall as well as the minute fracture diagnosis was correct compared to the autopsy results.

In order to further quantify location and congruence between autopsy and CT scan we selected five cases, and their 3-dimensional fracture registrations based on the first reading of the CT scan data and on the autopsy were merged. We did this by performing a 3-dimensional fracture registration at the autopsy by tracing the fractures using a digitiser (Patriot® Polhemus, US). The CT scan data were transferred to Mimics®, a software-programme which allows single slice editing and segmentation, enabling us to segment the fractures as seen on the CT images. The two obtained data sets, from the autopsy and the CT scan, were transferred to DesignCAD 3D Max 15®, a computer aided design package, and merged (see figure 1a, b and c).

At the autopsy the majority of the cases (12/14) comprised linear cranial fractures. There was also a case with a depressed fracture in the vault and one case with a local comminut fracture in the occiput. In half the cases several separate fractures were present per case, e.g., a linear fracture involving the posterior fossa and a separate fracture involving the medial fossa. Also more than half (n=9) of the fractures comprised a varying number of ramifications (n=1-5), which at the autopsy were seen as un-dislocated hairline fractures. Only a few of all the fractures were dislocated (n=4) and the fracture width varied from 4 mm - below 1 mm. Suture diastasis was involved in 5 cases and involved the lambdoid, squamous and sphenofrontal suture.

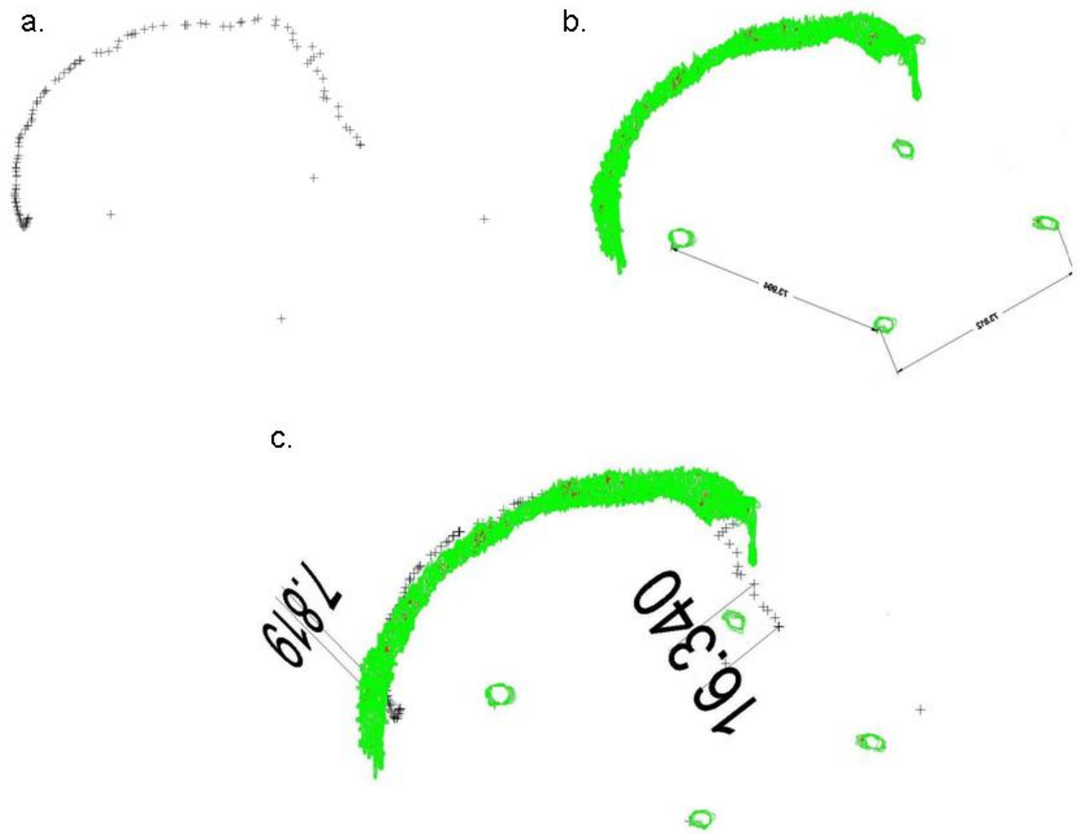


Figure 1a, b and c.

3-dimensional data set from case #6 with the digitised fracture at the autopsy (a), the segmented fracture from the CT image (b) and the merged two data sets.

The dimensions are in mm and represent only some of the measurements. The 2-dimensional representation of the 3-dimensional image causes distortion.

Results

It was seen at the autopsy that the basal fossae and the vault were affected in 34 instances (see table 1 and figure 2). The anterior and medial fossae were affected bilaterally in half the cases, while bilateral fractures in the posterior fossa only occurred once. Fractures involving the anterior fossa bilaterally (cases #6, #7, #13) never crossed the midline. The unilateral fractures in the anterior fossa (cases #1, #2, #11) were, except from one (case #11), continuations of fractures from the medial fossae (cases #1, #2) and were located in the sphenoid. Fractures involving the medial fossae (cases #1-7, #10-13) were separate fractures in two cases (cases #10, #13) but were mostly continuations of fractures from the posterior fossa (cases #5, #6, #11) or the vault (cases #1-4, #7). Four of the bilateral fractures in the medial fossae traversed the sella turcica (cases #3-5, #12).

Fractures	Base			Vault	Total
	Anterior fossa	Medial fossa	Posterior fossa		
Unilateral	4	5	7	5	21
Bilateral	3	6	1	3	13
Total	7	11	8	8	34

Table 1. Case based number of fractures in the anatomic entities of the neurocranium

The anatomic localisation and extent of the fractures was diagnosed completely during the first reading of the MPR CT images in two of the fourteen cases (cases #8, #14) (see figure 2). Case #8 comprised a simple linear fracture in the occipital bone oriented anterior-posteriorly. The fracture in case #14 was depressed, oriented anterior-posteriorly and located in the vault. In ten cases (#1-6, #9-12) there was a partial fracture diagnosis based on the MPR CT images, but the overall fracture system was recognized.

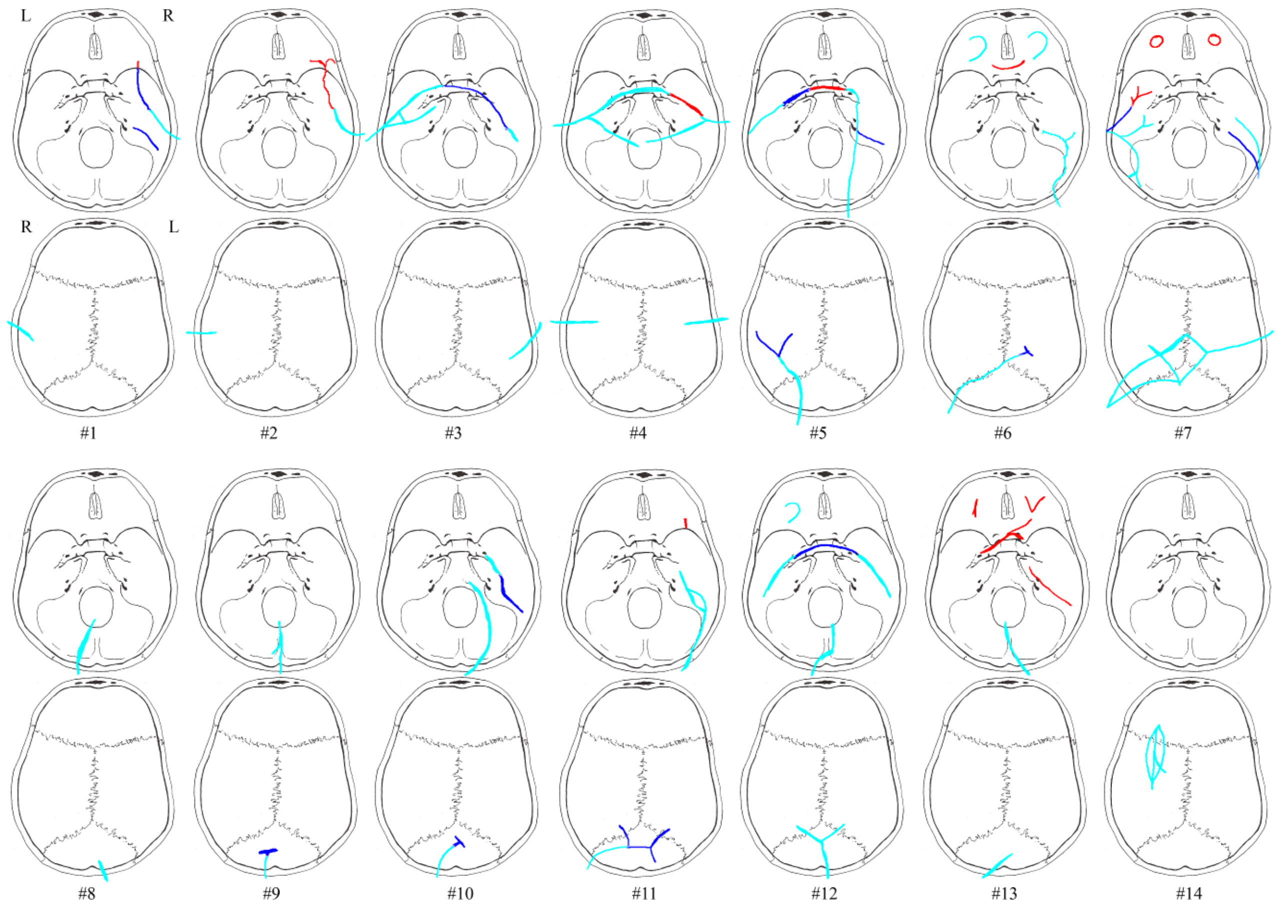


Figure 2. Registration of the case based fracture congruity between autopsy and CT.
The red colour represents the autopsy results, while the blue colours represent the result of the first CT reading (light blue) and the second CT reading (dark blue).

Table 2 shows the quantification of the fractures extent as measured by digitiser at the autopsy compared to the measurements performed on the CT scans after the first reading. The table shows that up to 50% of the full extent of the fractures was missed in one case (case #1). The missed fractures were hairline fractures. In cases #9, #6 and #11 the T- and H-shaped hairline fractures of the impact point was missed. In cases #11, #6 and #1 the hairline fractures located in the medial fossa, both in the petrous bone and the sphenoid, were not diagnosed. Case #14 represented the only depressed fracture in the material and in that case the diagnosis was correct.

Case no.	Digitiser (cm)	CT (cm)	Digitiser - CT subtraction sum (cm)	Anatomic localisation of missed fractures
#9	13.4	8.3	5.1	Occipital bone T-shaped hairline fracture
#11	22.2	17.5	4.7	Petrous bone, minor wing of the sphenoid (~1 cm each) and H-shaped fracture in the occiput
#6	20.4	18.1	2.3	Parietal bone (0.6 cm) and petrous bone (1.7 cm)
#1	22.1	10.3	11.8	Petrous bone ~3 cm and the great wing of the sphenoid (~8.8 cm)
#14	6.7 (length) 2.4 (width)	5.8 (length) 1.7 (width)	0.9 (length) 0.7 (width)	Depression fracture of the parietal bone

The fracture of the eyeloft in case no. 6 was not digitised

Table 2. Comparison of the digitised fracture length to the fracture length as measured on CT images of the first reading

By performing the second reading of the MPR and MIP CT images of 13 of the 14 cases (case #13 was excluded) the fractures of the cases #1, #3, #10 and #12 were diagnosed completely. In one case (case #7) important information, regarding contre-coup fractures, was missed on the CT-scan since fractures of the eye-loft in the anterior fossae were not diagnosed.

The missed fractures on the MPR CT images were characterised by being un-dislocated hairline fractures or ramifications of the wider fractures. Not surprisingly most of the missed fractures were located in the basal medial and anterior fossae (see table 3). Using thick MIP reconstructed CT images at the second evaluation did not facilitate the diagnosis of fractures in the minor wings of the sphenoid nor in the pars orbitalis of the frontal bone. The greatest advantage of using thick MIP reconstructed CT images was achieved in the medial fossa and in the vault when visualising ramifications related to impact points (see figure 3). In the medial fossa, using thick MIP improved the diagnostic frequency of fractures in the petrous part of the temporal bone (see figure 4) and the greater wings of the sphenoid by approximately 50%. The main fractures in the basal posterior fossa and the vault, except from five ramifications (cases #5, #6, #9-11), were diagnosed in the first evaluation. The ramifications were associated to impact points and were therefore important for the forensic casework. During the second evaluation, the usage of curved MPR on the CT images made the diagnosis of two of the ramifications possible (case #5 and #11) while the remaining ramifications were diagnosed by using thick MIP (case #6, #9 and #10).

Region	Anterior fossa		Medial fossa			Posterior fossa	Vault			Total
Bone	Frontal	Sphenoid	Temporal	Sphenoid	Sphenoid	Occipital	Frontal	Parietal	Temporal	
	Pars orbitalis	Minor wings	Petrous	Greater wings	Sella turcica				Pars squamosa	
Autopsy	7	5	15	15	4	8	1	12	9	76
1st CT reading	3	0	6	5	2	8	1	9	8	42
2nd CT reading	3[a]	0	11	11	3	8	1	12	9	58

[a]One case with two fractures of the eyeloft did not undergo the second evaluation

Table 3. Number of fractures in each bone as diagnosed by autopsy versus CT-scan

In several cases there were indications of fracture on the CT images with fluid in the mastoid cells (case #1, #4, #10, #12, #13) which at the autopsy always was associated with fracture in the same petrous bone. In four of these cases there was also fluid in the sphenoid sinus on the CT images (case #4, #12, #13) and/or the ethmoid sinus (case #1, #4, #12). In two cases fracture of the sinus walls was diagnosed on the CT image. In only one of these cases an associated fracture in the anterior fossa was not diagnosed at the autopsy (case #4).

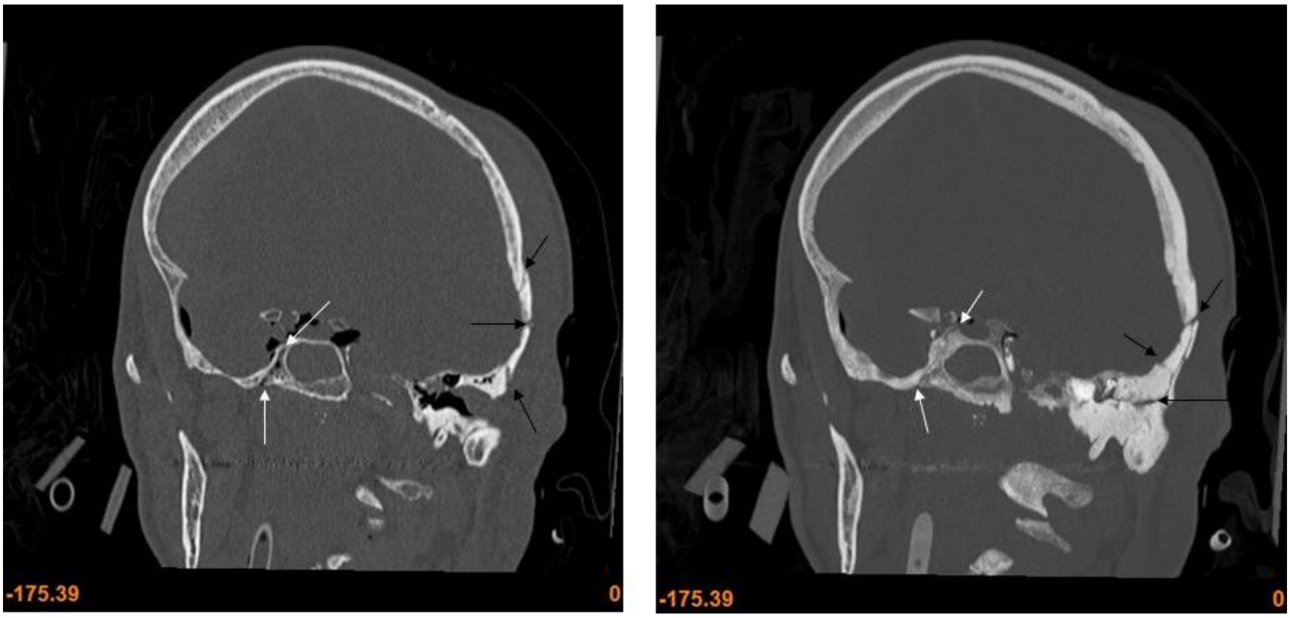


Figure 3. MPR (right) and MIP (left) coronal images of fractures in the left temporal bone and right great wing of the sphenoid.

The MIP provides a very good overview of the extension of the fractures. The fractures in the temporal bone are indicated by black arrows and the fractures in the great wing of the sphenoid are indicated by white arrows.

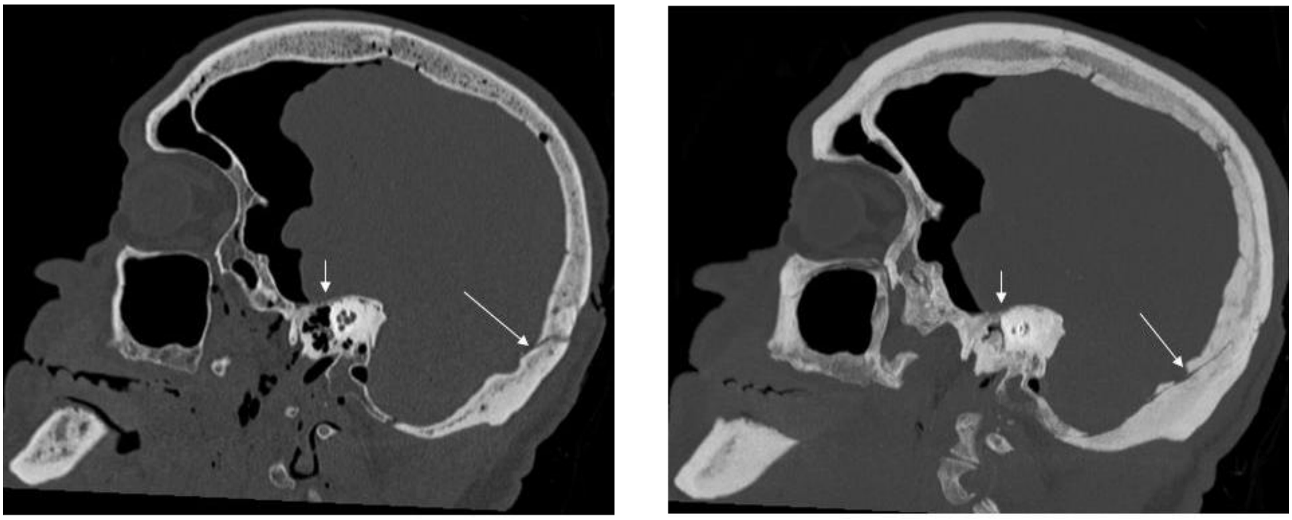


Figure 4. MPR (right) and MIP (left) sagittal images of fractures in the occipital bone and petrous part of the temporal bone.

The MIP provides an overview of the fractures extension and the hairline fracture in the petrous (short white arrow) and occipital bone (long white arrow).

Discussion

During the last years CT scanning of the head for forensic purposes has become widely used to visualize lesions or pathological changes prior to autopsy (67;68;80). Attempts have been made to use the acquired data for detecting causal relationships, either by illustrating and interpreting lesions based on CT images (69;81) and other tools (75), or by using the data to attempt biomechanical analysis (136) to analyze lesions.

The CT scan based recognition of fractures located in the basal cranial fossae and also the cranial vault is important both in the clinical setting regarding treatment efficiency (133;137;138) and in medico-legal material in order to be able to analyze injury mechanisms. However, in clinical settings the diagnosis of hairline fractures is mostly not essential as long as there are no clinical symptoms or complications (139). The medico-legal material in this study reflected the trauma severity with a fracture involvement of the medial fossa in 80% of the cases, which in this study was an area in which fracture diagnosis was difficult. Often both the pars petrosa of the temporal bone and the sphenoid bone were affected simultaneously either unilaterally or bilaterally and there were also a few cases with trans-sphenoidal fractures resulting in involvement of both fossa, which in clinical studies is interpreted as the result of severe head injury (32;124;140-142). Unger et al. (137) found in a clinical study that fractures of the cranial base predominantly were located in the sphenoid bone and to some extent in the temporal bone. In this study most fractures were identified in the greater wings of the sphenoid involving the orbital surface while fractures of the cerebral and temporal surfaces were less common. This finding might be related to the difficulties exemplified in this study in visualising these fractures on CT images. In our study none of the isolated fractures of the minor wing were diagnosed, which is in concordance with the study of Unger et al. (137) in which only a few fractures of the minor wings of the sphenoid were diagnosed.

With the combination of MIP, MPR and in some instances curved MPR, the identification of fractures at possible impact points was deemed acceptable. It is known that widths of linear fractures at impact sites can be narrower than at locations further away from impact in the same case (59). The recognition of a possible characteristic fracture corresponding to the impact point in the cranium and the correlation to possible scalp lesions and instruments is important for the casework, both from a biomechanical (59) and a forensic viewpoint.

The results implied difficulties regarding diagnosis of fractures involving the anterior fossa. In all our cases the fractures were confined to either side of the eye-loft without midline crossing and were forensically interpreted as being the result of an impact to the back of the head, i.e. contre-coup fractures of the eye-loft (128;129;143;144). In most clinical studies fractures of the eye-loft are associated with trauma to the facial or frontal region (25;145-147) producing transverse and longitudinal fractures (28;29) and we are not aware of clinical studies which mention these characteristic fractures after occipital impact. In a forensic routine setting both fracture of the anterior fossa and lesions of the cerebral temporal and frontal lobes in conjunction with occipital impact would be regarded as contre-coup lesions and thereby indicative of this specific injury mechanism. Further studies are needed to elucidate how often cerebral lesions and/or fractures of the eye-loft occur in impacts to the back of the head.

The difficulties regarding diagnosis of fractures involving the anterior and medial fossa is also known in the clinical setting (133). Schuknecht et al. (1) stress the use of correct protocols when attempting to diagnose fractures of the bones in the medial and anterior fossa (thin collimation (0.75 - 1 mm) and 2D MPR with contiguous 2 mm slices in the axial and coronal plane) and especially high resolution (0.5 - 0.75 mm) for evaluation of the pars petrosa of the temporal bone. Philipp et al. (148) found that thin MPR obtained from thin collimation (2 x 0.5 mm) was superior in subtle fracture detection compared to collimation of 4 x 1 mm in midline facial fractures.

Other 3-dimensional reconstructions aside from MIP (2) were not used in this study since the diagnostic improvement by using these reconstructions for visualizing non-dislocated and hairline fractures was not considered to be substantial compared to the 2-dimensional MPR images conf. (145;149;150). However recent studies have shown a diagnostic improvement by using Volume Rendering reconstructions for particularly pathological changes in the temporal bone (151). The use of high-resolution MPR's based on 0.625 mm collimations in a problem-based manner has also been found to improve the diagnostic frequency (130).

In this study we also wanted to try to more precisely measure the differences in determining fracture extent based on either CT scanning (MPR) and by direct inspection at autopsy. We were able to do this in five cases, and to our knowledge this represents the first such attempt at direct quantification. Fracture length discrepancies were thus measureable for hairline fractures. We feel that such precise quantification is necessary if CT data is to be used in future forensic, biomechanical injury modelling and Finite Element Analysis of minor fracture systems. One perspective of these techniques is the ability to perform retrograde injury modelling based on the specific case at hand, thereby complementing the general model based approach (see Raul et al. for an overview)(82). While finite element models in forensics and accident analysis already have been applied to injury simulation (84;152;153), the retrograde analyses will depend much on the correct capture of the full fracture extent and impact area. Capturing less than half of the full fracture extent will necessarily result in a lower calculated impact force, and not capturing the fracture pattern correctly may also result in a wrong interpretation of the causative injury. Clearly there is a need to extend the quantification to a larger sample and other cranial fracture patterns. Further studies of standard models and simulations are also necessary to accumulate data on head injury biomechanics and validate the head models (152).

An indication for a fracture being present involving the basal cranial fossae can be the identification of intra cranial air (154;155), fluid in the sinuses (156) or opacification of the mastoid cells (130). This was also the case in our material and these pathological changes led to fracture diagnosis in most of these cases. Connor et al (130) found that the specific use of high-resolution MPR's upon diagnosis of basal cranial fractures or indications hereof (opacified mastoid cells, etc.) on 5 mm axial images led to a higher diagnostic frequency. In our material there was also one case with fluid level in the sphenoid and ethmoid sinuses in conjunction with an occipital impact. There was no associated fracture of the anterior fossa. Fractures of the sinus walls are difficult to diagnose during an autopsy and in these cases CT images are of great advantage. Our material was too small to explore whether fractures of the sinus walls could be associated with impacts in the occiput and how often they occur without associated fracture of the anterior or medial fossa diagnosed during the autopsy. Geserick et al. (143) found in a prospective study that the orbital medial wall, roof and basal wall contained contre-coup fractures relating to occipital impacts. Also, other authors have found fractures of the orbital roof in similar cases (128;129). It remains to be established how often fluid in the mastoids or the sinus is associated to fractures and whether this finding in the sinus alone is as relevant as contre-coup fractures in the eye-loft for possibly differentiating between a blow to the head or impact to the moving head (e.g. fall) (129).

Collaboration with a radiologist (BHB) increased the diagnostic frequency of the cranial fractures. During the second reading the difference between a clinical and forensic approach towards diagnosis of cranial fractures was clearly demonstrated. This emphasized the fact that forensic radiology should be an interdisciplinary specialty which will be dependent on input and knowledge from both specialties to evolve further (65;72).

Conclusion and future directions

The aim of this series of studies (I-IV) was firstly to describe and analyze the occurrence and origin of cranial fractures caused by blunt trauma on the basis of a contemporary medico-legal autopsy material, thereby providing up-to-date knowledge for basic forensic interpretations, including forensic post-mortem radiology and future biomechanical studies. This enabled us, secondly to analyze the diagnostic congruity between autopsy and CT-scan regarding craniocerebral injury and to assess forensically important characteristics of cranial fractures as visualized on post-mortem CT scan compared to the autopsy. The results may have implications for the further development of forensic post-mortem CT-scan as an equal to forensic pathology.

Study I and II were carried out to examine the occurrence and origin of cranial fractures caused by blunt force in a Danish medico-legal material over the course of a 6-year period (1999-2004). Study I provided the baseline characteristics of this forensically important group. The male:female ratio was 3:1. It became apparent that 37.5% of the medico-legally autopsied traffic related deaths had sustained a cranial fracture, affecting especially the young adults. Also falls were a prominent trauma type throughout every age range. A positive test for alcohol was common in ground level falls and falls down stairs, especially in the group of chronic alcohol abusers. The linear fractures were the most common cranial fractures. Most of the fractures were accompanied by moderate to severe intracranial injuries or/and severe injuries of other organ systems resulting in the fatal outcome and reflecting the medico-legal material.

In study II a characterization of the cranial fractures caused by blunt force was attempted by focusing on the cranial fractures, the scalp injuries and the related trauma type. Regarding the associations between impact area and subsequent cranial fracture the study basically validated earlier studies, especially the seminal studies by Rawling and Gurdjian et al. (26;29;30). By adding the trauma type as a parameter, an advancement of the analysis was obtained. Thereby we were able to establish common impact regions for various trauma types and relate these to induced cranial fractures. The most characteristic impact region and fracture type was found in the group of ground level falls. Moreover a very common involvement of the cranial base became evident.

On the basis of the acquired material for study I and II several questions have arisen. Future research might help answer them and could, amongst others, focus on various issues. In study II it was not possible to match 10% of the scalp injuries with cranial fractures, suggesting that a certain amount of the fractures were induced by indirect impact. This could be subject to a further examination. The same issue as mentioned above also concerns the basilar fractures and the analysis of their associated impacts. A future prospective study could focus on the observed injuries combined with a thorough biomechanical evaluation regarding trauma type and feasible associated trauma mechanism. Finally, it would be of interest to perform an extended analysis of the intracranial injuries, e.g. by combining microscopic examination; forensic autopsy and CT-scan or MRI. Besides that, an obvious focus could be on an overall analysis of medico-legal cases with blunt trauma to their head in order to survey the extra cranial, cranial and intracranial injuries, regardless of cranial fracture.

Knowledge about cranial fracture occurrence, origin, and morphology was provided by the results from study I and II forming the basis for a further analyses by forensic autopsy compared to post-mortem CT-scan.

The advantages and limitations of the craniocerebral CT-scan in an environment with routine post-mortem CT-scan were illustrated in study III. The study exemplified the existing forensic-radiologic diagnostic challenges for craniocerebral injuries and the importance of using the correct technical CT-scan setting depending on the pathology. It became apparent that one of the main challenges was to be able to diagnose non-dislocated fractures and fractures located in the cranial base. Standardization of the autopsy and CT-scan reports along with forensic or radiologic training of the personnel performing and diagnosing CT-scans is needed, in order to heighten the diagnostic accuracy and frequency. Systematic research at least across the forensic and radiologic specialty is required in order to establish and fasten the role of radiologic examination modalities in forensic pathology.

Study IV demonstrated how forensically and biomechanically important minor fracture systems to a large extent were diagnosed on CT images by using various reconstructions (MPR and MIP) and by collaborating with a radiologist. This led to an improvement of the diagnostic possibilities regarding forensically important information, e.g. visualizing non-dislocated fractures; and impact points in the cranium. Difficulties remained in the minute diagnosis of hairline fractures located especially in the anterior or medial fossae. We were able to quantify data by merging digitised data from the autopsy and data from the CT-scan. The merges were performed based on fracture diagnosis prior to the second evaluation by a radiologist and it must be assumed that the amount of missed fractures would have decreased if CT-scan data had been used after the second reading. The results showed that the agreement between the autopsy results and the CT image regarding minor fracture systems still needs to be improved. If retrograde trauma analysis, Finite Element Analysis and individual head modelling in the future are to be based on CT-scan data a consistent and reliable fracture diagnosis is essential and the fractures extent and course must be captured fully by CT scan.

Studying the field of forensic post-mortem radiology combined with the forensic autopsy has led to many questions and ideas on how post-mortem radiology on several levels might be evolved further. Future larger blinded diagnostic studies on head injuries or other cases important in forensic pathology, could evaluate the congruence between autopsy and CT scan images further. This requires a precise definition of which radiologic and autoptic findings and diagnoses are deemed sufficient to make a sound diagnosis, which is acceptable also in court. Both focused research studies and routine post-mortem scans, which correlate radiology diagnoses with macroscopic and microscopic examination or other accepted methods, e.g. forensic gas analysis to distinguish between air embolism and gas formation due to putrefaction, would provide an extended, profitable work platform in forensic pathology. A close collaboration between radiologists and radiologic technicians with the forensic pathologists in the routine scan and during research projects would provide greater insight and create inspiring environments. The use of a forensic radiology database, as proposed by Aghayev et al.(135), both on a local, national and international level would lead to an increase in knowledge and form a basis for future multi-Center studies. Finally, new generation CT scanners with the technical ability to produce isotropic volume data may probably improve the diagnostic frequency (157;158).

Post-mortem CT- and MRI scan is still a new field in forensic pathology and a close national and international collaboration between the institutes using these imaging methods would be extremely beneficial and accelerate the process of integrating the radiological methods in forensic pathology. The use of these imaging methods in forensic pathology could create a link to various other disciplines, e.g. biomechanical injury analysis, providing new aspects and opportunities to further evolve this discipline. Routine post-mortem CT-scans need to be performed with a well defined purpose, by tailoring the use of scan-protocols, and especially image reconstructions, in a problem-based-manner.

Reference List

(1) Schuknecht B, Graetz K. Radiologic assessment of maxillofacial, mandibular, and skull base trauma. European Radiology 2005; 15(3):560-568.

(2) Medina L. Three-Dimensional CT Maximum Intensity Projections of the Calvaria: A New Approach for Diagnosis of Craniosynostosis and Fractures. American Journal of Neuroradiology 2000; 21:1951-1954.

(3) Jennett B. Epidemiology of head injury. Archives of the Diseases of Childhood 1998; 78(5):403-406.

(4) Engberg AW, Teasdale T. Traumatic brain injury in Denmark 1979-1996. A national study of incidence and mortality. European Journal of Epidemiology 2001; 17(5):437-442.

(5) Steudel WI, Cortbus F, Schwerdtfeger K. Epidemiology and prevention of fatal head injuries in Germany - trends and the impact of the reunification. Acta Neurochirurgica 2005; 147(3):231-242.

(6) Tiret L, Hausherr E, Thicoipe M, Garros B, Maurette P, Castel JP et al. The Epidemiology of Head Trauma in Aquitaine (France), 1986: A Community-Based Study of Hospital Admissions and Deaths. International Journal of Epidemiology 1990; 19(1):133-140.

(7) Sosin D, Sacks J, Smith S. Head-Injury Associated Deaths in the United States from 1979 to 1986. The Journal of the American Medical Association 1989; 262(16):2251-2255.

(8) Cohadon F, Richer E, Castel J. Head injuries: incidence and outcome. Journal of Neurological Sciences 1991; 103:S27-S31.

(9) Bruns J, Hauser WA. The Epidemiology of Traumatic Brain Injury: A Review. Epilepsia 2003; 44(s10):2-10.

(10) Tagliaferri F, Compagnone C, Korsic M, Servadei F, Kraus J. A systematic review of brain injury epidemiology in Europe. Acta Neurochirurgica 2006; 148(3):255-268.

(11) Adekoya N, Thurman D, White D, Webb K. Surveillance for Traumatic Brain Injury Deaths - United States, 1989-1998. CDC Surveillance Summaries 2002; 51 (SS10)(MMWR December 6, 2002):1-16.

(12) Masson F, Thicoipe M, Aye P, Mokni T, Senjean P, Schmitt V et al. Epidemiology of Severe Brain Injuries: A Prospective Population-Based Study. Journal of Trauma 2001; 51:481-489.

(13) Murray G, Teasdale G, Braakman R, Cohadon F, Dearden M, et al. The European Brain Injury Consortium Survey of Head Injuries. Acta Neruochirurgica 1999; 1999(141):223-236.

(14) Jiang Jy, Feng H, Fu Z, Guo-yi G, Wei-ping L, Wei-guo L et al. Violent head trauma in China: report of 2254 cases. Surgical Neurology 2007; 68(Supplement 2):S2-S5.

(15) Myhre M, Grøgaard J, Dyb G, Sandvik L, Nordhov M. Traumatic head injury in infants and toddlers. Acta Pædiatrica 2007; 96:1159-1163.

(16) Engberg AW, Penninga EI, Teasdale TW. [Nordic accident classification system used in the Danish National Hospital Registration System to register causes of severe traumatic brain injury]. Ugeskrift for Laeger 2007; 169(45):3856-3860.

(17) Sundstrøm T, Sollid S, Wester K. [Deaths from traumatic brain injury in the Nordic countries, 1987-2000]. Tidsskrift Norsk Lægeforening 2005; 125:1310-1312.

(18) Kleiven S, Peloso PM, Holst Hv. The epidemiology of head injuries in Sweden from 1987 to 2000. Injury Control & Safety Promotion 2003; 10(3):173.

(19) Ingebrigtsen Tor, Mortensen Kim, Bertil Romner. The Epidemiology of Hospital-Referred Head Injury in Northern Norway. Neuroepidemiology 1998; 17:139-146.

(20) Rutty GN. Are Invasive Autopsies Necessary? Forensic Science, Medicine and Pathology 2005; 1-2:71-73.

(21) Nelson E, Melton J3, Annegers J, Laws ER, Offord K. Incidence of skull fractures in Olmsted County, Minnesota. Neurosurgery 1984; 15(3):318-324.

(22) Johnstone A, Zuberi S, Scobie W. Skull fractures in children: a population study. Journal of Accident and Emergency Medicine 1996; 13:386-389.

(23) Panourias I, Skiadas P, Sakas D, Marketos S. Hippocrates: A Pioneer in the Treatment of Head Injuries. Neurosurgery 2005; 57(1):181-189.

(24) Krantz KPG, Löwenhielm CGP. Head and Neck Injuries. Acta Neurochirurgica 1986; Suppl. 36:47-50.

(25) Hooper K. Injuries of the skull. Patterns of Acute Head Injury. 1969. 21-30.

(26) Rawling LB. Fractures Of The Skull. The Surgery Of The Skull And Brain. 1 ed. London: Oxford Medical Publications; 1912. 68.

(27) LeCount ER, Apfelbach C. Pathologic anatomy of Traumatic Fractures of Cranial Bones and Concomitant Injuries. Journal of the American Medical Association 1920; 74:501-511.

(28) Vance B. Fractures of the Skull - Complications and Causes of Death: A Review of 512 Necropsies and of 61 Cases studied Clinically. Archives of Surgery 1927; 14:1023-1092.

(29) Gurdjian ES, Webster JE, Lissner HR. The Mechanism of Skull Fracture. Radiology 1950; 54:313-339.

(30) Gurdjian ES, Webster JE, Lissner HR. Observations on Prediction of Fracture Site in Head Injury. Radiology 1953; 60(2):226-235.

(31) Freytag E. Autopsy Findings in Head Injuries from Blunt Forces - Statistical Evaluation of 1367 Cases. Archives of Pathology 1963; 75:402-413.

(32) Menon A, Pai VK, Rajeev A. Pattern of fatal head injuries due to vehicular accidents in Mangalore. Journal of Forensic and Legal Medicine 2008; 15(2):75-77.

(33) Zentner J, Franken H, Löbbeke G. Head injuries from bicycle accidents. Clinical Neurology and Neurosurgery 1996; 98:281-285.

(34) Yavuz MSM, Asirdizer MM, Cetin GM, Gunay Balci YM, Altinkok MM. The Correlation Between Skull Fractures and Intracranial Lesions Due To Traffic Accidents. American Journal of Forensic Medicine & Pathology 2003; 24(4):339-345.

(35) Törö K, Hubay M, Sótonyi P, Keller E. Fatal traffic injuries among pedestrians, bicyclists and motor vehicle occupants. Forensic Science International 2005; 151(2-3):151-156.

(36) Törö K, Szlávik N, Mèszáros Á, Dunay G, Soós M, Keller É. Jumping and falling death in children, adolescents, and young adults. Journal of Clinical Forensic Medicine 2006; 13:129-134.

(37) Hitosugi M, Takatsu A, Shigeta A. Injuries of Motorcyclists and Bicyclists Examined at Autopsy. The American Journal of Forensic Medicine and Pathology 1999; 20(3):251-255.

(38) Depreitere B, Van Lierde C, Maene S, et al. Bicycle-related head injury: a study of 86 cases. Accident Analysis and Prevention 2004; 36(4):561-567.

(39) Demetriades D, Murray J, Martin M, Velmahos G, Salim A, Alo K et al. Pedestrians injured by automobiles: Relationship of age to injury type and severity. Journal of the American College of Surgeons 2004; 199(3):382-387.

(40) Boström L, Nilsson B. Pedestrians who Required Admission to Hospital after Collisions with Motor Vehicles in Sweden from 1987 to 1994. European Journal of Surgery 2001; 167:810-815.

(41) Copeland A. Pedestrian Fatalities - The Metropolitan Dade County Experience, 1984-1988. The American Journal of Forensic Medicine and Pathology 1991; 12(1):40-44.

(42) Ryan G, McLean A, Vilenius A, Kloeden C, Simpson D, Blumbergs P et al. Brain injury patterns in fatally injured pedestrians. Journal of Trauma 1994; 36(4):469-476.

(43) Richter D, Hahn M, Ostermann PAW, Ekkernkamp A, Muhr G. Vertical deceleration injuries: a comparative study of the injury patterns of 101 patients after accidental and intentional high falls. Injury 1996; 27(9):655-659.

(44) Türk E, Tsokos M. Pathologic Features of Fatal Falls From Height. The American Journal of Forensic Medicine and Pathology 2004; 25(3):194-199.

(45) Yagmur Y, Güloglu C, Aldemir M, Orak M. Falls from flat-roofed houses: a surgical experience of 1643 patients. Injury 2004; 35:425-428.

(46) Scalea T, Goldstein A, Phillips T, Sclafani S, Panetta T, McAuley J et al. An Analysis of 161 Falls from a Height: The 'Jumper Syndrome'. The Journal of Trauma 1986; 26(8):706-712.

(47) Steedman D. Severity of free-fall injury. Injury 1989; 20:259-261.

(48) Velmahos G, Demetriades D, Theodorou D, Cornwell III E, Belzberg H, Asensio J et al. Patterns of Injury in Victims of Urban Free-Falls. World Journal Surgery 1997; 21:816-821.

(49) Høidrup S, Sørensen T, Grønbæk M, Schroll M. Incidence and characteristics of falls leading to hospital treatment: a one-year population surveillance study of the Danish population aged 45 years and over. Scandinavian Journal of Public Health 2003; 31:24-30.

(50) Cummins BH, Potter JM. Head Injury Due To Falls From Heights. Injury 1970; 2(1):61-64.

(51) Hein P, Schulz E. [Accident-fall induced craniocerebral injury]. Beitrag Gerichtliche Medizin 1989; 47:447-450.

(52) Preuß J, Padosch SA, Dettmeyer R, Driever F, Lignitz E, Madea B. Injuries in fatal cases of falls downstairs. Forensic Science International 2004; 141(2-3):121-126.

(53) O'Neill TW, Varlow J, Silman AJ, Reeve J, Reid DM, Todd C et al. Age and sex influences on fall characteristics. Annals of Rheumatic Diseases 1994; 53(11):773-775.

(54) Hartshorne N, Harruff R, Alvord EJr. Fatal Head Injuries in Ground-Level Falls. The American Journal of Forensic Medicine and Pathology 1997; 18(3):258-264.

(55) Helling TS, Watkins MR, Evans LL, Shook JW, Van Way CW. Low Falls: An Underappreciated Mechanism of Injury. Journal of Trauma 1999; 46(3):453-456.

(56) Shkrum M, Ramsay D. Craniocerebral and Vertebrospinal Trauma. In: Amy Thau, editor. Forensic Pathology of Trauma - Common problems for the pathologist. Totowa, New Jersey: Humana Press Inc.; 2007. 519-606.

(57) Yoganadan N, Pintar FA. Biomechanics of temporo-parietal skull fracture. Clinical Biomechanics (Bristol, Avon) 2004; 19:225-239.

(58) Morris A, Hassan A, Mackay M, Hill J. Head Injuries In Lateral Impact Collisions. Accident Analysis and Prevention 1995; 27(6):749-756.

(59) Yoganandan N, Pintar F, Sances A Jr, Walsh P R, Ewing C L, Thomas D J et al. Biomechanics of Skull Fracture. Journal of Neurotrauma 1995; 12(4):659-668.

(60) Voo L, Kumaresan S, Pintar F, Yoganandan N, Sances AJr. Finite-element models of the human head - Review. Medical & Biological Engineering & Computing 1996; September:375-381.

(61) Delye H, Verschueren P, Depreitere B, Verpoest I, Berckmans D, Vander Sloten J et al. Biomechanics of Frontal Skull Fracture. Journal of Neurotrauma 2007; 24(10):1576-1586.

(62) Verschueren P, Delye H, Depreitere B, Van Lierde C, Haex B, Berckmans D et al. A new test set-up for skull fracture characterisation. Journal of Biomechanics 2007; 40(15):3389-3396.

(63) McElhaney JH. Mechanical properties of cranial bone. Journal of Biomechanics 1970; 3:495-511.

(64) Wood JL. Dynamic response of human cranial bone. Journal of Biomechanics 1971; 4:1-12.

(65) O'Donnell C, Rotman A, Collet S, Woodford N. Current status of routine post-mortem CT in Melbourne, Australia. Forensic Science, Medicine and Pathology 2007; 3:226-232.

(66) Thali M, Yen K, Schweitzer W, Vock P, Dirnhofer R. Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem MSCT and MRI. Journal of Forensic Science 2003; 48(2):386-403.

(67) Poulsen K, Simonsen J. Computed tomography as routine in connection with medico-legal autopsies. Forensic Science International 2007; 171(2-3):190-197.

(68) Leth P, Christoffersen S. Computertomografi anvendt ved retsmedicinske obduktioner. Ugeskrift for læger 2008; 170(6):444-447.

(69) Bauer M, Polzin S, Patzelt D. The use of clinical CCT images in the forensic examination of closed head injuries. Journal of Clinical Forensic Medicine 2004; 11(2):65-70.

(70) Molina K, Nichols J, DiMaio VJM. The Sensitivity of Computed Tomography (CT) Scans in Detecting Trauma: Are CT Scans Reliable enough for Courtroom Testimony? The Journal of Trauma 2007; 63(3):625-629.

(71) Hoey B, Cipolla J, Grossmann M, McQuay N, Shukla P, Stawicki S et al. Postmortem Computed Tomography, "CATopsy", Predicts Cause of Death in Trauma Patients. The Journal of Trauma 2007; 63(5):979-986.

(72) Yen K, Lövblad KO, Scheurer E, Ozdoba C, Thali MJ, Aghayev E et al. Post-mortem forensic neuroimaging: Correlation of MSCT and MRI findings with autopsy results. Forensic Science International 2007; 173(1):21-35.

(73) Paperno S, Riepert T, Krug B, Rothschild MA, Schultes A, Staak M et al. Prospektive Untersuchung zur Wertigkeit der postmortalen Computertomographie im Vergleich zur Autopsie. RöFo - Fortschritte auf dem Gebiet der Röntgenstrahlen und der Bildgebenden Verfahren 2005;(01):130-136.

(74) Jackowski C, Dirnhofer S, Thali M, Aghayev E, Dirnhofer R, Sonnenschein M. Postmortem diagnostics using MSCT and MRI of a lethal streptococcus group A infection at infancy: a case report. Forensic Sci Int 2005; 151(2-3):157-163.

(75) Bolliger S, Thali M, Ross S, Buck U, Naether S, Vock P. Virtual autopsy using imaging: bridging radiologic and forensic sciences. A review of the Virtopsy and similar projects. European Radiology 2008; 18(2):273-282.

(76) Thali MJ, Braun M, Wirth J, Vock P, Dirnhofer R. 3D surface and body documentation in forensic medicine: 3-D/CAD Photogrammetry merged with 3D radiological scanning. Journal of Forensic Science 2003; 48(6):1356-1365.

(77) Roberts I, Benbow E, Bisset R, Jenkins J, Lee S, Reid H et al. Accuracy of magnetic resonance imaging in determining cause of sudden death in adults: comparison with conventional autopsy. Histopathology 2003; 42:424-430.

(78) Ezawa H, Yoneyama R, Kandatsu S, Yoshikawa K, Tsujii H, Harigaya K. Introduction of autopsy imaging redefines the concept of autopsy: 37 cases of clinical experience. Pathology International 2003; 53:865-873.

(79) Besenski N. Traumatic injuries: imaging of head injuries. European Radiology 2002; 12(6):1237-1252.

(80) Thali M, Jackowski C, Oesterhelweg L, Ross S, Dirnhofer R. VIRTOPSY - The Swiss virtual autopsy approach. Legal Medicine 2007; 9:100-104.

(81) Oehmichen M, Gehl HB, Meissner C, Petersen D, Höche W, Gerling I et al. Forensic pathological aspects of postmortem imaging of gunshot injury to the head: documentation and biometric data. Acta Neuropathologica 2003; 105(6):570-580.

(82) Raul JS, Deck C, Willinger R, Ludes B. Finite-element models of the human head and their applications in forensic practice. International Journal of Legal Medicine 2008; 122(5):359-366.

(83) O'Riordain K, Thomas PM, Phillips JP, Gilchrist M. Reconstruction of real world head injury accidents resulting from falls using multibody dynamics. Clinical Biomechanics 2003; 18:590-600.

(84) Raul J, Baumgartner D, Willinger R, Ludes B. Finite element modelling of human head injuries by a fall. International Journal of Legal Medicine 2006; 120:212-218.

(85) Hayes W, Erickson M, Power E. Forensic Injury Biomechanics. Annual Review Biomedicine England 2007; 9:55-86.

(86) Viceconti M, Zannoni C, Testi D, Cappello A. A new method for the automatic mesh generation of bone segments from CT data. Journal of Medical Engineering & Technology 1999; 23(2):77-81.

(87) Young P, Beresford-West T, Coward S, Notarberardino B, Walker B, Abdul-Aziz A. An efficient approach to converting three-dimensional image data into highly accurate computational models. Philosophical Transactions of The Royal Society 2008; 366:3155-3173.

(88) Gelaude F, Vander Sloten J, Lauwers B. Accuracy assessment of CT-based outer surface femur meshes. Computer Aided Surgery 2008; 13(4):188-199.

(89) Bandak FA, Vander Vorst MJ, Stuhmiller LM, Mlakar PF, Chilton WE, Stuhmiller JH. An Imaging-based Computational and Experimental Study of Skull Fracture: Finite Element Model Development. Journal of Neurotrauma 1995; 12:679-688.

(90) Bangash M, Al-Obaid Y, Bangash F, Bangash T. Trauma - An Engineering Analysis with Medical Case Studies Investigation. 1 ed. Berlin Heidelberg New York: Springer; 2007. 343-365.

(91) Guan Y, Zhang J, Yoganandan N, Pintar F, Muszynski C, Gennarelli T. Automating 3D meshing method for patient-specific modelling. Biomedical Sciences Instrumentation 2006; 42:199-204.

(92) Jacobsen C, Lynnerup N. Craniocerebral Trauma - Congruence between Post-mortem Computed Tomography Diagnoses and Autopsy Results - A 2 year retrospective study. submitted 2008.

(93) Gurdjian E. Deformation Studies Of The Skull: Mechanisms Of Skull Fracture. Impact Head Injury - Mechanistic, Clinical and Preventive Correlations. 1. ed. Springfield, Illinois: Charles C Thomas; 1975. 113-138.

(94) Borchard A, Nordmann O, editors. Der Bruch der Schädelbasis. Verhandlungen Der Deutschen Gesellschaft Für Chirurgie; Berlin: Julius Springer; 1939.

(95) Saint-Martin P, Bouyssy M, Bathellier S, Sarraj S, O'Byrne P. Homicide in Tours (Indre-et-Loire, France): A four-year review. Journal of Clinical Forensic Medicine 2006; 13(6-8):331-334.

(96) Henderson JP, Morgan SE, Patel F, Tiplady ME. Patterns of non-firearm homicide. Journal of Clinical Forensic Medicine 2005; 12(3):128-132.

(97) Rogde S, Hougen H, Poulsen K. Homicide by Blunt Force in 2 Scandinavian Capitals. The American Journal of Forensic Medicine and Pathology 2003; 24(3):288-291.

(98) Ericsson A, Thiblin I. Injuries inflicted on homicide victims
A longitudinal victiminologic study of lethal violence. Forensic Science International 2002; 130:133-139.

(99) Ambade VN, Godbole HV. Comparison of wound patterns in homicide by sharp and blunt force. Forensic Science International 2006; 156(2-3):166-170.

(100) Brink O, Vesterby A, Jensen Jr. Pattern of injuries due to interpersonal violence. Injury 1998; 29(9):705-709.

(101) Murphy G. "Beaten to death" - An Autopsy Series of Homicidal Blunt Force Injuries. The American Journal of Forensic Medicine and Pathology 1991; 12(2):98-101.

(102) Christiansen S, Rollman D, Leth P, Thomsen J. Children as victim of homicide 1975-2005. Ugeskrift for Laeger 2007; 169(47):4070-4074.

(103) Burns A, Goodall E, Moore T. A study of suicides in Londonderry, Northern Ireland, for the year period spanning 2000-2005. Journal of Forensic and Legal Medicine 2008; 15(3):148-157.

(104) Henderson JP, Mellin C, Patel F. Suicide - A statistical analysis by age, sex and method. Journal of Clinical Forensic Medicine 2005; 12(6):305-309.

(105) Rogde S, Hougen HP, Poulsen K. Suicides in two Scandinavian capitals -- A comparative study. Forensic Science International 1996; 80(3):211-219.

(106) Schmidt P, Müller R, Dettmeyer R, Madea B. Suicide in children, adolescents and young adults. Forensic Science International 2002; 127(3):161-167.

(107) Murray D, de Leo D. Suicidal Behavior by Motor Vehicle Collision. Traffic Injury Prevention 2007; 8(3):244-247.

(108) Demetriades D, Gkiokas G, Velmahos GC, Brown C, Murray J, Noguchi T. Alcohol and illicit drugs in traumatic deaths: Prevalence and association with type and severity of injuries. Journal of the American College of Surgeons 2004; 199(5):687-692.

(109) Tsai V, Anderson C, Vaca F. Young Female Drivers in Fatal Crashes: Recent Trends, 1995-2004. Traffic Injury Prevention 2008; 9:65-69.

(110) Christophersen AS, Ceder G, Kristinsson J, Lillsunde P, Steentoft A. Drugged driving in the Nordic countries-: a comparative study between five countries. Forensic Science International 1999; 106(3):173-190.

(111) Bernhoft IM, Steentoft A, Johansen SS, Klitgaard NA, Larsen LB, Hansen LB. Drugs in injured drivers in Denmark. Forensic Science International 2005; 150(2-3):181-189.

(112) Behrensdorff I, Steentoft A. Medicinal and illegal drugs among Danish car drivers. Accident Analysis & Prevention 2003; 35(6):851-860.

(113) Edna T. Alcohol influence and head injury. Acta Chir Scand 1982; 148:-209.

(114) Yartsev A, Langlois NEI. A comparison of external and internal injuries within an autopsy series. Medicine, Science and Law 2008; 48(1):51-56.

(115) Vanezis P. Interpreting bruises at necropsy. Journal of Clinical Pathology 2001; 54(5):348-355.

(116) Kremer C, Racette S, Dionne C-A, Sauvageau A. Discrimination of Falls and Blows in Blunt Head Trauma: Systematic Study of the Hat Brim Line Rule in Relation to Skull Fractures. Journal of Forensic Science 2008; 53(3):716-719.

(117) Macpherson B, Macpherson P, Jennett B. CT Evidence of Intracranial Contusion and Haematoma in Relation to the Presence, Site and Type of Skull Fracture. Clinical Radiology 1990; 42:321-326.

(118) Voigt GE, Skold G. Ring fractures of the base of the skull. Journal of Trauma 1974; 14(6):494-505.

(119) Gan YC, Charkravarty D, Flint G. Ring fracture of the skull base: case report and review of the literature. British Journal of Neurosurgery 2002; 16(3):300-303.

(120) Rowbotham GF. The mechanisms of injuries of the head. Acute Injuries Of The Head. Fourth ed. Edinburgh and London: E.& S.Livingstone Ltd; 1964. 56-69.

(121) Jennett B, Teasdale G, Galbraith S, Pickard J, Grant H, Braakman R et al. Severe head injuries in three countries. Journal of Neurology, Neurosurgery, and Psychiatry 1977; 40:291-298.

(122) Tallon J, Ackroyd-Stolarz S, Karim S, Clarke D. The epidemiology of surgically treated acute subdural and epidural hematomas in patients with head injuries: a population-based study. Canadian Journal of Surgery 2008; 51(5):339-345.

(123) McElhaney JH, Hopper RH Jr., Nightingale RW, Myers B. Mechanisms of Basilar Skull Fracture. Journal of Neurotrauma 1995; 12(4):669-678.

(124) Harvey F, Jones A. "Typical" Basal Skull Fracture of Both Petrous Bones: An Unreliable Indicator of Head Impact Site. Journal of Forensic Sciences 1980; 25(2):280-286.

(125) Gordon I, Shapiro HA, Berson SD. Regional injuries of medico-legal importance; Head injuries. Forensic Medicine - A Guide To Principles. Third ed. Edinburgh London Melbourne and New York: Churchill Livingstone; 1988. 252-269.

(126) Leestma J, Grcevic N. Impact Injuries to the Brain and Head. In: Kirkpatrick JB, editor. Forensic Neuropathology. 1 ed. New York: Raven Press; 1988. 184-252.

(127) Gupta SM, Chandra JM, Dogra T. Blunt force lesions related to the heights of a fall. The American Journal of Forensic Medicine and Pathology 2004; 3(1):35-43.

(128) Hein PM, Schulz E. Contrecoup fractures of the anterior cranial fossae as a consequence of blunt force caused by a fall. Acta Neurochirurgica 1990; V105(1):24-29.

(129) Hirsch C, Kaufman B. Contrecoup skull fractures. Journal of Neurosurgery 1975; 42(May):530-534.

(130) Connor SEJ, Flis C. The contribution of high-resolution multiplanar reformats of the skull base to the detection of skull-base fractures. Clinical Radiology 2005; 60(8):878-885.

(131) Jacobsen C, Lynnerup N. Cranial fractures caused by blunt trauma to the skull - A retrospective analysis of medicolegal autopsies in Denmark 1999-2004. Scandinavian Journal of Forensic Sciences 2008; accepted for publication

(132) Hausmann R, Vogel C, Seidl S, Betz P. Value of morphological parameters for grading of brain swelling. International Journal of Legal Medicine 2006; 120(4):219-225.

(133) Provenzale J. CT and MR imaging of acute cranial trauma. Emergency Radiology 2007; 14(1):1-12.

(134) Wardlaw J, Statham P. How often is hemosiderin not visible on routine MRI following traumatic intracerebral haemorrhage. Neuroradiology 2000; 42:81-84.

(135) Aghayev E, Staub L, Dirnhofer R, Ambrose T, Jackowski C, Yen K et al. Virtopsy - The concept of a centralized database in forensic medicine for analysis and comparison of radiological and autopsy data. Journal of Forensic and Legal Medicine 2008; 15(3):135-140.

(136) Myers JC, Okoye MI, Kiple D, Kimmerle EH, Reinhard KJ. Three-dimensional (3-D) imaging in post-mortem examinations: elucidation and identification of cranial and facial fractures in victims of homicide utilizing 3-D computerized imaging reconstruction techniques. International Journal of Legal Medicine 1999; 113(1):33-37.

(137) Unger JM, Gentry LR, Grossman JE. Sphenoid fractures: prevalence, sites, and significance. Radiology 1990; 175(1):175-180.

(138) Herbella FAM, Mudo M, Delmonti C, Braga FM, Del Grande JC. "Raccoon Eyes" (periorbital haematoma) as a sign of skull base fracture. Injury 2001; 32:745-747.

(139) Goh K, Ahuja A, Walkden S, Poon W. Is routine computed tomographic (CT) scanning necessary in suspected basal skull fractures? Injury 1997; 28(5-6):353-357.

(140) Kienstra M, Loveren HV. Anterior Skull Base Fractures. Facial Plastic Surgery 2005; 21(3):180-186.

(141) Joslyn JN, Mirvis SE, Markowitz B. Complex fractures of the clivus: diagnosis with CT and clinical outcome in 11 patients. Radiology 1988; 166(3):817-821.

(142) West OC, Mirvis SE, Shanmuganathan K. Transsphenoid basilar skull fracture: CT patterns. Radiology 1993; 188(2):329-338.

(143) Geserick G, Prokop O, Kruse C. [Frakturen der knöchernen Orbita bei stumpfem Schädeltrauma mit Contrecoup-Verletzungen]. Kriminal- und Forensische Wissenschaften 1980; 39:53-57.

(144) Lignitz E, Henn V. New autopsy signs in violent death. Forensic Science International 2007; 165(2-3):172-177.

(145) Buitrago-Tellez CH, Schilli W, Bohnert M, Alt K, Kimmig M. A comprehensive classification of craniofacial fractures: postmortem and clinical studies with two- and three-dimensional computed tomography. Injury 2002; 33(8):651-668.

(146) Asano T, Ohno K, Takada Y, Suzuki R, Hirakawa K, Monma S. Fractures of the Floor of the Anterior Cranial Fossa. The Journal of Trauma, Injury, Infection and Critical Care 1995; 39(4):702-706.

(147) Exadaktylos A, Sclabas G, Smolka K, Rahal A, Andres R, Zimmermann H et al. The Value of Computed Tomographic Scanning in the Diagnosis and Management of Orbital Fractures Associated with Head Trauma: A Prospective, Consecutive Study at a Level I Trauma Center. The Journal of Trauma, Injury, Infection and Critical Care 2005; 58:336-341.

(148) Philipp M, Funovics M, Mann F, Herneth A, Fuchsjaeger M, Grabenwoeger F et al. Four-Channel Multidetector CT in Facial Fractures: Do we need 2 x 0.5 mm collimation? American Journal of Radiology 2003; 180:1707-1713.

(149) Brüning R, Quade R, Keppler V, Reiser M. 3-D-CT reconstructions in fractures of the skull base and facial skeleton. RöFo - Fortschritte auf dem Gebiet der Röntgenstrahlen und Bildgebenden Verfahren 1994; 160(2):113-117.

(150) Ali Q, Dietrich B, Becker H. Patterns of skull base fracture: a three-dimensional computed tomographic study. Neuroradiology 1994; 36:622-624.

(151) Fatterpekar G, Doshi A, Dugar M, Delman B, Naidich T, Som P. Role of 3D CT in the Evaluation of the Temporal Bone. RadioGraphics 2006; 26(Special Issue):S117-S132.

(152) Marjoux D, Baumgartner D, Deck C, Willinger R. Head injury prediction capability of the HIC, HIP, SIMon and ULP criteria. Accident Anlalysis and Prevention 2008; 40:1135-1148.

(153) Roth S, Raul J, Willinger R. Biofidelic child head FE model to simulate real world trauma. Computer Methods and Programs in Biomedicine 2008; 90:262-274.

(154) Cihangiroglu M, Ozdemir H, Kalender O, Ozveren F, Kabaalioglu A. Transverse sinus air after cranial trauma. European Journal of Radiology 2003; 48(2):171-174.

(155) Betz BW, Wiener MD. Air in the temporomandibular joint fossa: CT sign of temporal bone fracture. Radiology 1991; 180(2):463-466.

(156) Laasonen E, Servo A, Sumuvori H. Sphenoid Sinus Fluid Level in Skull-Base Fractures. European Journal of Radiology 1982; 2:5-7.

(157) Parizel P, Van Goethem J, Özsarlak Ö, Maes M, Phillips C. New developments in the neuroradiological diagnosis of craniocerebral trauma. European Journal of Radiology 2005; 15:569-581.

(158) Lane J, Lindell E, Witte R, DeLone D, Driscoll C. Middle and Inner Ear: Improved Depiction with Multiplanar Reconstruction of Volumetric CT Data. RadioGraphics 2006; 26(1):115-125.

Summary

The PhD thesis consists of four original papers. The overall aim of the study was to increase the knowledge about cranial fracture characteristics and the causative blunt trauma types, together with an analysis of the benefits of forensic post-mortem Computed Tomography (CT) in these cases. We did this by analysing the cases with cranial fracture caused by blunt trauma in a Danish medico-legal material. The focus was on the relationship between trauma type, the anatomic localisation of scalp injuries and head impact combined with an analysis of the topography and extent of the cranial fractures. Forensic post-mortem CT was assessed as a diagnostic tool in the medico-legal routine work and as a means to produce data for creating future biomechanical models. In these studies, the focus was on the diagnostic correlation between CT and autopsy in the routine work as well as a more detailed methodological study.

Paper I is a retrospective, descriptive study providing the summary statistics of cranial fractures caused by blunt trauma to the head in a Danish medico-legal material from 1999-2004.
Paper II is based on the same material as paper I and is a retrospective, descriptive study of cranial fractures caused by blunt trauma correlating scalp injuries with impact regions, cranial fractures and trauma type.
Paper III is a retrospective study correlating CT-scan based diagnoses of cranial and cerebral lesions with autopsy diagnoses in 56 cases.
Paper IV is a prospective study correlating the identification of cranial fractures by two CT-scan evaluations with the fracture identification at autopsy in 14 cases.

In the first paper we aimed at describing the trauma type, the resulting head impact and the characteristics of cranial fractures caused by blunt force. By analysing 428 cases we found that the main trauma types were, as expected, traffic accidents and falls and that the most common fracture types were linear (~60%). Most of the fractures were accompanied by moderate to severe intracranial injuries or/and severe injuries of other organ systems.

The second paper was based on the same material as the first and this study focused on impact regions, fracture characteristic and trauma types. These parameters were quite variable regarding victims of traffic accidents depending very much on accident circumstances. Victims in traffic accidents often sustained impacts in the frontal and lateral region, which induced approximately equally many linear

fractures and other fracture types. Fall victims, however, often sustained occipital impacts resulting in linear fractures. With increasing fall height the fractures became more extensive, although a few extensive fractures also were sustained in ground level falls. Homicide victims mainly sustained impacts in the lateral regions of the head causing a variety of fractures. Generally, we were able to conclude that impacts in one single anatomic region of the head, which mainly occurred in falls, mostly produced linear fractures while involvement of several regions, which mainly occurred in traffic accidents, more often produced severe fractures.

In the third paper we analyzed the role of post-mortem CT-scanning specifically regarding the diagnosis of cranial fractures and cerebral lesions in a routine setting correlated with autopsy diagnoses. We found that approximately 61% of the skull fracture diagnoses based on the CT images were correct, while there was a partial diagnosis in 16% of the cases and a total miss in 23% of the cases. The diagnostic agreement of fractures involving the cranial base was highest in the posterior fossa and lowest in the frontal fossa. Regarding brain injuries the diagnostic agreement varied from 0-79%. The results showed a decreasing diagnostic coherence between non-dislocated fractures recognized on CT-scans as opposed to autopsy.

The fourth paper was partially generated by the findings of the third paper. We focused on the diagnostic congruence between fractures on CT-scans and autopsy both in regards to the identification of forensically important information and the future development of biomechanical models for retrograde trauma analysis. We performed an analysis of 14 cases with cranial fractures by carefully recording the fractures as diagnosed on CT scans post processed with Multiplanar reconstruction (MPR) and Maximum Intensity Projection (MIP), as well as by detailed recording of the fractures at autopsy (drawing + photos). Furthermore, we tried to quantify the differences by tracing the fractures as seen at autopsy using a 3-dimensional digitizer and merging this 3-dimensional data set with a 3-dimensional reconstruction of fractures diagnosed on CT scan.

We found that the forensically important fracture systems to a large extent were diagnosed on CT images using MPR and MIP reconstruction. Difficulties remained in diagnosing hairline fractures in the anterior and medial fossa which may have implications for biomechanical modelling of the trauma. Collaboration with a radiologist proved to be essential and should be incorporated in forensic institutes.

In conclusion, the results describe the blunt trauma types causing cranial fractures in a forensic material. Further, we have demarcated the application of CT for analysing cranial fractures in forensic pathology. The findings may provide useful knowledge for the forensic interpretation of cranial fractures, both on CT scan and by autopsy, as well as for future biomechanical model development.

Resumé

Ph.d.-afhandlingen omfatter fire originale artikler. Afhandlingens overordnede formål var at øge viden om kraniefrakturers karakteristik og den forårsagende traumetype ved stump vold sammen med en vurdering af brugen af retsmedicinsk post-mortem Computer Tomografi (CT) i disse sager. Dette blev dels gjort ved at analysere sager med kraniefrakturer forårsaget af stump vold i et dansk retsmedicinsk materiale. Fokus var på relationen mellem traumetype, de eksterne læsioners og anslagspunkters anatomiske lokalisation, kombineret med en analyse af topografien og udbredelsen af kraniefrakturerne. Endvidere blev retsmedicinsk post-mortem CT vurderet som diagnostisk redskab i det retsmedicinske rutinearbejde, og som et redskab til at producere data for i fremtiden at kunne udvikle biomekaniske modeller. I disse studier var fokus på den diagnostiske korrelation mellem CT og obduktionen, både i det daglige arbejde samt i et detaljeret metodologisk studie.

Artikel I er et retrospektivt, deskriptivt studie af kraniefrakturer forårsaget af stump vold mod hovedet i et dansk retsmedicinsk materiale i årene 1999-2004.
Artikel II er et retrospektivt, deskriptivt studie af kraniefrakturer forårsaget af stump vold mod hovedet, som korrelerer den anatomiske lokalisation af de eksterne læsioner og anslagspunkter med topografien og udbredelsen af kraniefrakturer og traumetype.
Artikel III er et retrospektivt studie, som korrelerer CT skannings baserede diagnoser af kranie- og hjernelæsioner med obduktionsdiagnoser i 56 sager.
Artikel IV er et prospektivt studie som korrelerer identifikationen af kraniefrakturer baseret på fraktur identifikation ved to forskellige CT skannings evalueringer samt ved obduktion i ialt 14 sager.

Den første artikel havde til formål at beskrive kraniefrakturer opstået ved stump vold, den forårsagende traumetype, de extra kranielle læsioner og de intrakranielle læsioner. Ved at analysere 428 sager beskrev vi at 37,5% af alle retsmedicinsk obducerede ofre for traffikulykker havde pådraget sig en kraniefraktur. De hyppigst forårsagende traumetyper, var som forventet, hovedsagligt trafikulykker og fald. De hyppigste frakturtyper var lineære (~60%). De fleste frakturer blev ledsaget af moderat-svære hjernelæsioner og/eller læsioner af andre organsystemer.

Den anden artikel baserede på samme materiale som den første og i dette studie fokuseredes på anslagspunkter, frakturkarakteristik og traumetyperne. Disse parametre var variable vedrørende trafikofre, ulykker og afhængig af ulykkesomstændighederne. Trafikofre pådrog sig ofte anslag i den

frontale og i de laterale regioner, resulterende i, omtrent ligeligt fordelte, lineare og andre brud. Faldofre fik ofte anslag i baghovedet resulterende i lineære frakturer. Frakturerne var mere udbredte ved øget faldhøjde, selvom der også sås enkelte udbredte frakturer ved fald på samme niveau. Drabsofre havde hovedsaligt anslag i hovedets laterale regioner, hvilket resulterede i varierende kraniefrakturmønstre. Generelt kunne vi konkludere, at anslag i en enkelt anatomisk region af hovedet, som det typisk sås ved fald, oftest forårsagede lineære brud, mens anslag som involverede flere regioner, som det typisk sås ved trafik ulykker, oftest forårsagede udbredte brud.

I den tredje artikel analyserede vi den post-mortelle CT-skannings rolle, specifikt med hensyn til diagnosen af kraniefrakturer og cerebrale læsioner, under daglige retsmedicinske arbejdsforhold og korrelerede dette med obduktionsdiagnoser. Vi fandt, at cirka 61% af kraniefraktur diagnoserne baseret på CT-skanningerne var korrekte, mens der var en partiel diagnose i 16% af sagerne og en ukorrekt diagnose i 23% af sagerne. Den diagnostiske overensstemmelse af frakturerne som involverede kraniebunden var højest i den posteriore del og lavest i den anteriore del. Vedrørende cerebrale læsioner varierede den diagnostiske overensstemmelse mellem 0-79%. Resultaterne viste en aftagende diagnostisk sammenhæng mellem ikke-dislocerede frakturer identificeret på CT-skanningen i forhold til obduktionen.

Den fjerde artikel var delvist genereret af resultater fra den anden artikel. Vi fokuserede på den diagnostiske kongruens mellem frakturer påvist på CT-skanningen og ved obduktionen, både med hensyn til identifikationen af retsmedicinsk betydende fund og den fremtidige udvikling af en biomekanisk model til retrograd traumeanalyse. Vi foretog en detaljeret analyse af 14 sager med kraniefrakturer, ved præcist at nedfælde frakturerne både som de blev diagnosticeret på CT-billeder rekonstrueret Multiplanart og med Maximum Intensity Projection (MIP) og som de blev identificeret ved obduktionen (tegning og fotos). Derudover prøvede vi at kvantificere differenserne mellem frakturerne ved at spore disse under obduktionen ved brug af en 3-dimensionel såkaldt digitiser. Dette 3-dimensionelle datasæt blev fusioneret med en 3-dimensionel rekonstruktion af frakturerne identificeret på CT-skanningen. Vi fandt, at de retsmedicinsk vigtige fraktursystemer oftest blev diagnosticeret på CT-skanninger ved brug af MPR og MIP rekonstruktioner af skanningerne. Det var vanskeligt at identificere hårlinie frakturer i den anteriore og mediale del af kraniebunden, hvilket kunne have implikationer for en biomekaniske modellering af traumet. Samarbejdet med en radiolog viste sig at være essentiel og bør inkorporeres hos de retsmedicinske institutter.

Sammenfattende beskrev resultaterne hvorledes stump vold forårsager kraniefrakturer i et retsmedicinsk materiale. Endvidere vurderede vi kritisk brugen af CT for at analysere kraniefrakturer i retsmedicinsk patologi. Resultaterne tilfører ny viden for den retsmedicinske fortolkning af kraniefrakturer, både på CT-skannings billeder som ved obduktionen, og endvidere for den fremtidige biomekaniske model udvikling.

Ethics

The study was approved by the Ethics Committee for Copenhagen and Frederiksberg KF 01-154/04.

Cranial fractures caused by blunt trauma to the skull

A retrospective analysis of medico-legal autopsies in Denmark from 1999-2004

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ABSTRACT Blunt trauma to the head with subsequent cranial, external cranial and intracranial lesions occurs in many types of trauma. The aim of this study was to focus on the cranial fractures caused by blunt trauma in a medico-legal material. In the years 1999-2004 428 cases with cranial fractures caused by blunt trauma were autopsied at the medico-legal institutes in Denmark. In order to report the summary statistics of the cases with cranial fracture, we retrospectively registered basic data from the autopsy and toxicology report, including the manner of death, the circumstances regarding the trauma, the autopsy findings regarding the cranial fractures, external lesions and intracranial lesions. The male:female ratio was 3:1. Accidents were the most common manner of death (n=372), mainly comprising traffic accidents (n=242) and falls (n=109). Traffic related deaths with cranial fracture comprised ~37% of all the medico-legally autopsied traffic related deaths in this period, while deaths with cranial fractures caused by homicides and suicides constituted less than 5% of the cases. Approximately 40% of the cases tested positive in the blood alcohol analyses and toxicology analyses for various substances. The external lesions were mostly sugillations and subgaleal hematomas (n=502). Linear fractures of the cranium constituted ~60% of the total material, while comminute fractures constituted 14.5%. The most common intracranial lesions were subarachnoid haemorrhages and contusions (~70%). Subdural haemorrhages occurred in ~23% and epidural haemorrhages in ~5% of the cases. The epidural haemorrhages were mainly located on the right side of the head.

Keywords: **Cranial fracture, Trauma type, Blunt trauma**

INTRODUCTION

Injury is a leading cause of death in the young and middle aged in the western world [1] and blunt trauma to the head occurs in many trauma types. In most western countries head injuries are mainly caused by traffic related injuries [2]. In the years 1991-1993 the Danish incidence rate for cranial fractures was 7.1/100.000, while the annual incidence rate for patients hospitalized for brain injuries is approximately 157/100.000 with an annual mortality rate for brain injuries of approximately 10.7/100.000 [2]. A number of studies regarding head and brain injury exist [1,3-12,12-16], but to our knowledge there are only very few recent studies regarding cranial fractures caused by blunt trauma to the head and the corresponding trauma type [17,18]. The aim of this retrospective study was to provide the summary statistics and an up-to-date overview of all cases with cranial fracture regardless of cause of death as encountered in a Danish medico-legal material. The focus was on basic case data, including basic pathological description of the lesions and fractures.

MATERIAL AND METHODS

The study is based upon medico-legal autopsies performed at the forensic institutes in Denmark at Copenhagen, Århus and Odense, in the period 1999-2004. In this 6-year period a total of 8682 forensic autopsies were performed at the institutes; 4805 in Copenhagen, 2714 in Århus and 1163 in Odense (overall male/female ratio 2.5:1). The cases were selected by using databases at the institutes. Cases with fractures of only the facial skeleton, intracranial lesions without cranial fractures, and cases involving sharp trauma or cranial gun-shot wounds were excluded. This resulted in a total of 428 cases (Copenhagen 170/Odense 92/Århus 166), equivalent to ~5% of all the autopsies in the period.

By reviewing the autopsy reports, including the forensic toxicology report, we registered basic data, including the circumstances regarding the trauma, the autopsy findings regarding fractures in the neurocranium, the associated scalp lesions and the macroscopic intracranial lesions. If a microscopic examination of intracranial lesions was performed the results were not registered. The results of a forensic toxicology analysis (400 acid, neutral and basic drugs, tetrahydrocannabinol, cocaine, benzoylecgonine, methadone, amphetamines, opiates, benzodiazepines, buprenorphine and norbuprenorphine) and/or analysis of blood alcohol concentration (BAC) were registered. Results of a possible hospital analyses were registered in the autopsy reports and in these cases a forensic toxicology analyses had not been performed. All analyses were included for the general overview. For the detailed description of the results only the forensic analyses was included.

The cases were grouped by the manner of death into accident, homicide, suicide, natural and undetermined. These groups were sub-grouped into different types of trauma: Traffic related deaths, falls and the related height, hit/struck/crushed by blunt object and other trauma type.

RESULTS

Sex and age distribution

The material comprised 330 males (age span: below 1 year of age to 93 years; median: 40 years) and 98 females (age span: below 1 year of age to 89 years; median: 59 years) with a male:female ratio of 3:1 (see table 1). This disparity between the sexes was evident throughout all the age groups until the seventh decade, with a relatively larger male proportion killed in accidents and homicides. From 71 years of age the disparity between the sexes diminished.

Manner and cause of death

The largest group of cases were accidents (see figure and table 1), which comprised traffic accidents (n=242), falls (n=109), trauma by blunt object (n=14) and other accidents (n=7). A cranial fracture was sustained by 37.5% of all the medico-legally autopsied traffic related deaths (n=651) in this period, while the other accidents, including falls caused cranial fractures in 4.5% of all the medico-legally autopsied falls and other accidents. The share of traffic accidents was proportionally greatest in the age ranges 18-40 years. Among cases above 40 years of age, traffic accidents and the other

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Table 1. Characteristics of the included cases: manner of death, cause of death and trauma type.

Characteristics	n=428
Manner of death:	
Accidents	372
Homicides	26
Suicides	20
Natural death	3
Undetermined	7
Cause of death:	
Craniocerebral lesion	233
Craniocerebral lesion and other lesions	190
Undetermined	5
Trauma type:	
Traffic:	
Car occupant	103
Pedestrian	53
Bicycle riders	39
Motorcycle riders	32
Other traffic situations	26
Falls/jumps from heights:	
Ground level	48
2 - 3 metres	32
3 - 5 metres	16
above 5 metres	19
No height known	15
Hit/struck by blunt object and/or interpersonal violence:	
Hit/struck by blunt object	34
Blows and kicks	4
Other:	8

Figure 1. The manner of death distributed by age range and sex. "Others" include natural deaths and undetermined manner of death. The included groups are: Accident - traffic (vertical hatching); Accident - Fall (white); Accident - other (left-to-right oblique hatching); Suicide (horizontal hatching); Homicide (black); Others (right-to-left oblique hatching)

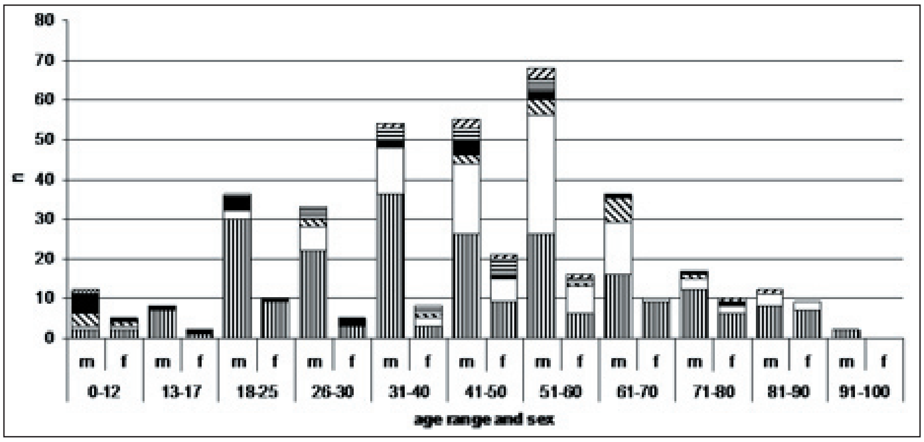
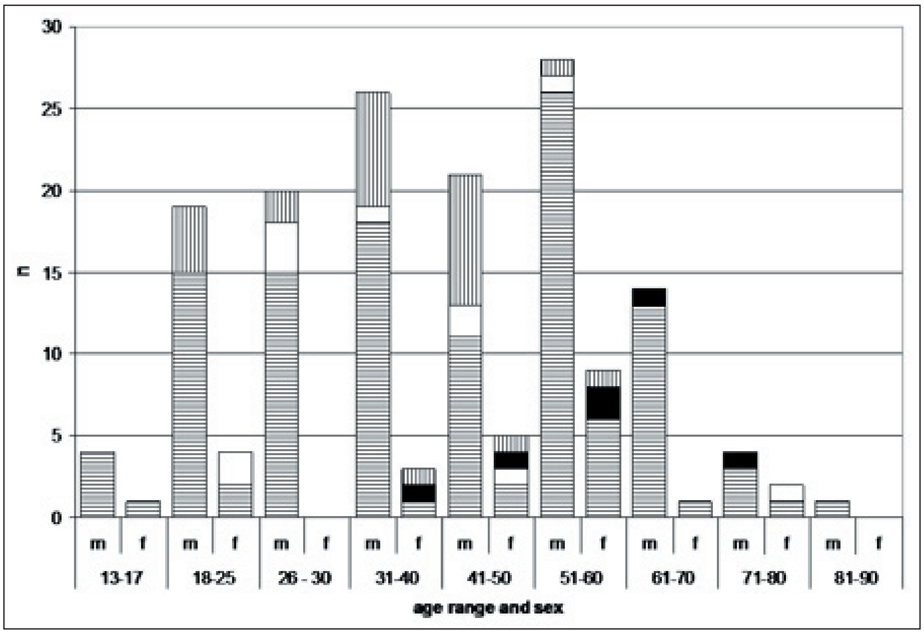


Figure 2. Number of cases with a positive test for alcohol, illicit drugs, and prescription drugs distributed by age range and sex. The included groups are: Alcohol (horizontal hatching); illicit drugs (white); prescription drugs (black); combination (vertical hatching)..



accident types were represented evenly. In the age group 81-90 the role in traffic changed, especially for females, from using motorised vehicles and bicycles to being a pedestrian with an increase in falls and being hit by motorised vehicles. Falls occurred throughout the age ranges; there were a few falls below the age of 12 years and a peak of falls at the age of 51-60 years.

The homicide cases with cranial fracture comprised 4.5% of the total material (n=26/428) and in most cases the head had been hit/struck with a blunt object, jumped upon or kicked (73%). Another mechanism was falls (~15%) in the course of interpersonal violence and three cases had been registered as "other mechanisms". Roughly one third of the homicide cases were female (n=7), which were distributed evenly through the age ranges, unlike the males in which a higher number of homicides occurred in the age range of 0-12 years and 41-50 years.

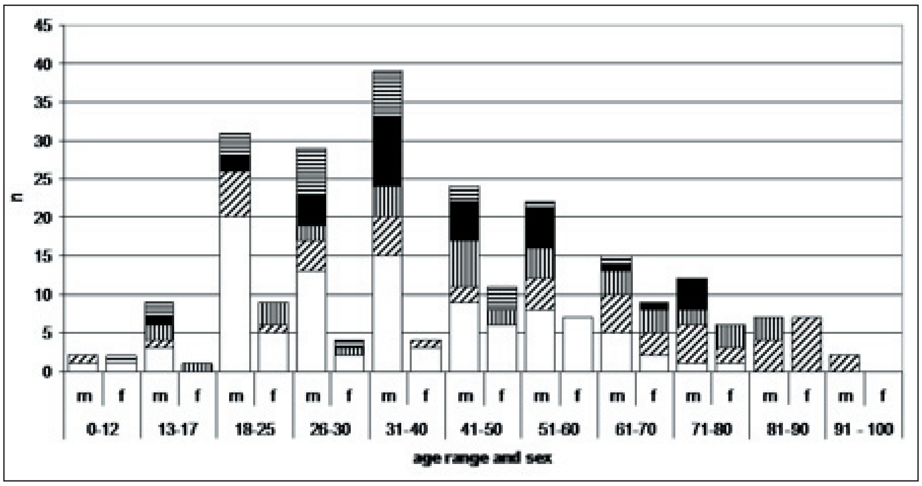
Of the 20 suicide cases (3.5% of the total material), half committed suicide by jumping from heights and half occurred in a traffic setting (four were car drivers, five were hit by train, one was hit by a truck). This occurred in the age ranges of 18-60 years for males and 31-60 years for females. There were three cases of natural death which all comprised sudden deaths due to a natural disease. In these cases the cranial fractures were the result of falls in relation to death and the cause of death was nonviolent. There were seven cases in which a manner of death was not determined; in three of the seven cases there was a suspicion of homicide versus accident, in one case suicide vs. accident and in three cases natural death vs. accident.

Overall, craniocerebral lesions were the sole cause of death given in approximately half the material (see table 1) and in nearly all the remaining cases polytrauma, e.g. the craniocerebral lesions were combined with substantial lesions of other organsystems. There was no difference in the cranial fracture characteristics of these two groups.

Alcohol and substance abuse

Forensic toxicology, including BAC analysis was performed in 207 cases. Furthermore in 107 cases a BAC analysis only was performed. In additional eighteen cases, hospitals had performed a BAC and toxicologic analysis. Based upon hos-

Figure 3. The activity during traffic accident distributed by age range and sex. The included groups are car occupant (white); pedestrian (right-to-left oblique hatching), cyclist (vertical hatching); motorcyclist (black); other (horizontal hatching).



pital and forensic analyses it was found that about half of the tested individuals (n=18/134, 48.8%) tested positive for various substances (see figure 2), with an overall male:female ratio of 6.5:1. For males there was a fairly even distribution throughout the age ranges until 60 years, whereas the number of females testing positive increased throughout the age range of 41-60 years. The BAC was above the legal driving limit of 0.05% in 40% of the cases (n=122/314).

Overall 116 individuals had a known history of alcohol abuse (n=83), illicit drugs (n=17), or a combination thereof (n=12), or of alcohol in combination with prescribed drugs (n=4). Half of the alcohol abusers tested positive for alcohol and/or illicit or prescription drugs at the time of death. Likewise most of the illicit drug abusers (82.4%) and half (56.3%) of the mixed substance abusers tested positive for various substances.

Trauma type: Traffic

In our material most cranial fractures were caused in traffic (n = 252 cases) (see figure 3). Car accidents formed the largest group with a declining frequency after the 31-40 year group. The car drivers were the car occupants which most often underwent a medico-legal autopsy. The second largest group were pedestrians (n=53), mostly hit by motorised vehicles, with a peak at the age of 18 to 30 (n=11) and 81 to 90 (n=11). Motor cyclists and bicycle riders (n=32/39) sustained cranial fractures most often by being hit or hitting other vehicles (n=23/30). They were distributed nearly evenly throughout the age ranges. There was seldom information whether cycle riders had used protective helmets. The group of other traffic related deaths consisted amongst others of plane (8 accidents) and train crashes (3 accidents/5 suicides). A BAC above the legal driving limit was found in 25 car drivers and 9 motor cyclists. Also 19 pedestrians and 7 cyclists tested positive for alcohol. Seven of the road users tested positive for illicit drugs.

Trauma type: Falls

Most falls had been classified as accidents (n=109/129). There were also ten suicides, five homicides, three natural deaths and three cases in which the manner of death was undetermined. In 116 cases there was a height specification (see table 1). Ground level falls and falls down stairs constituted 67.5% of all the falls and occurred mostly in domestic settings. Falls from buildings (n=10), ladders (n=4) and outdoors (n=1) were also represented. The suicidal jumps from heights were mostly from buildings, but also bridges and, in one case, a staircase. The fall height varied between 3 m to above 20 m. The individuals tested positive for alcohol in 38 of the fall cases (34 male, 4 female) and this was especially seen in ground level falls and falls involving stairs. Of these individuals 63% were known alcohol and/or illicit drug abusers (n=21 alcohol, n=3 alcohol and illicit drugs).

Trauma type:
Blunt interpersonal violence or violence by/with blunt object

This group (n=38, male=29, female=9) comprised 16 accidents and 22 homicides.

The accidents were characterised by several different trauma mechanisms resulting in crushing of the head by heavy objects (e.g., a television, tree-branches) and other mechanism. Five of these accidents were work-related and five happened during leisure activities outdoors.

Interpersonal violence (blows and kicks) or a blunt object was the mechanism in 22 homicides. Five of the cases were female adults and ten were male adults while the remaining cases were under the age of 14 years. A blunt object was used in 10 of the homicides. The type of object used varied greatly (e.g., a mannequin arm, a wooden log) and in five cases no information about the object used was available. Ten cases were with interpersonal violence, of which three cases were with witnessed jumping on/punching/ trampling or kicking to the head. Three children under the age of 14 died in the course of an extended suicide in which their father induced blunt trauma to their heads and afterwards caused an explosion of their home. (The cause of death could not be established in these cases.) Seven individuals tested positive for alcohol and three of the seven also for illicit drugs. The group also comprised six infants under the age of 12 months (two accidents and four homicides). Two sustained accidental cranial fractures by manual or instrumental force on the head during child birth. Four infants were killed in homicides and sustained their head injuries by being hit against an object, with an object or by being punched/kicked by primary and secondary caretakers.

Trauma type: Other

In eight cases there was no information about how the cases had sustained the craniocerebral injuries.

External cranial lesions

Almost all cases (398/428) had one or several scalp lesions. A total of 946 lesions were registered (see table 2). The most common lesions were sugillations or subgaleal hematomas, but severe burns (e.g. car occupants) and partial amputations also occurred. Bleeding from the auditory canal was in nearly all the cases (n=94) associated with a basilar cranial fracture. The mono- or biocular hematomas were associated with fracture of the

Table 2. The number of external lesions and signs of fracture.

External lesions and signs of fracture	n
Contusion wounds	244
Excoriations	162
Sugillations/subgaleal hematomas	502
Other lesions (e.g. burns)	38
Bleeding from auditory canal	96
Mono- or biocular hematomas	68

Table 3. The classification and number of cranial fractures.

Fractures of the neurocranium	n
Linear fractures	
Anterior-posterior orientation	*84*
Side-to-side orientation	*107*
Oblique orientation or combination	*60*
Subtotal	*251*
Other fracture types	
Depressed	*22*
Multiple	*22*
Spider web	*3*
Ring fracture	*15*
Comminute	*62*
Combination	*42*
Inconclusive	*11*
Subtotal	*177*
Total	428

bones comprising the anterior fossa in approximately 80% of the cases. In 30 of the cases (19 traffic related/10 falls/1 accident by blunt object) external lesions were not reported in the autopsy reports. Eleven of these cases had been hospitalized and treated prior to death and six survived for more than three days, which could have resulted in healing of minor external lesions prior to the autopsy. This means that in 19 cases no external lesions were registered, but it is possible that they were not correctly identified and registered by the pathologist.

Fractures of the neurocranium

Blunt trauma to the neurocranium had resulted in 428 fracture systems which consisted of a variety of different fracture types divided into linear fractures and other fracture types [19] (see table 3). The linear fractures comprised ~60% of the total material. The other fracture types ranged from involving small areas of the theca, e.g. depressed fracture to massive comminute fractures. Some of the other fracture types were combinations of the fracture groups, e.g., depressed fractures combined with multiple fractures or linear fractures and were therefore grouped separately (table 3).

The linear fractures were anatomically generally located equally in the base or both the base and the theca, while only a few fractures were located solely in the theca (see table 4). The other fracture types mostly involved both the base and the theca. The comminute fractures always involved both, while especially the ring fractures involved only the base. The so-called inconclusive fractures (in table 3) were cases in which the fracture description from the autopsy report did not allow a certain classification.

Intracranial lesions

In 371 cases 998 intracranial lesions were registered macroscopically during the autopsy (see table 5). Contusions and subarachnoid haemorrhages were found in approximately 70% of the cases while epidural haemorrhages occurred in only 5% of the cases. The frontal lobes sustained one-third of the contusions, while the temporal lobes and the cerebellum were affected in approximately 25% and 14% of the cases respectively.

Table 4. The anatomical localisation of linear fractures and other fracture types.

	Base and theca	Base	Theca	Total
Linear fractures	111	120	20	251
Other fracture types	126	34	17	177
All fracture systems	237	154	37	428

Table 5. The anatomical localisation of the registered intracranial lesions.

	SAH	EDH	SDH	Contusion	Laceration	Haemorrhage	Total
Frontal lobes	56	0	0	119	30	12	217
Temporal lobes	55	0	0	74	23	6	158
Parietal lobes	34	0	0	22	14	6	76
Occipital lobes	14	0	0	37	11	1	63
Cerebellum	69	0	0	45	19	15	148
Right hemisphere	86	16	46	16	7	6	177
Left hemisphere	81	4	52	7	9	6	159
Total	395	20	98	320	113	52	998

SAH - subarachnoid haemorrhage, EDH - extradural haemorrhage, SDH - subdural haemorrhage

Subarachnoid haemorrhage involving the hemispheres was seen in 42% of the cases, while localised subarachnoid haemorrhages involved the frontal and temporal cerebral lobes in approximately 14% of the cases respectively and the cerebellum in approximately 17% of the cases. The subdural haemorrhages were distributed evenly over both hemispheres, while epidural haemorrhages were more common over the right hemisphere. Approximately 80% of the epidural haemorrhages were located over the right hemisphere and were associated with mainly linear fractures of the right temporal and/or parietal bone and lesion of the middle meningeal artery. Cerebral haemorrhages occurred especially in the frontal lobes and the cerebellum.

DISCUSSION

While there are many epidemiological studies about head trauma and traumatic brain injury [1-16], we have found only few recent studies about cranial fractures [17,18]. Indeed, most of the extant knowledge about the pathology of cranial fracture arises from studies carried out in the beginning and the middle of the last century [19-23]. The epidemiological data from our medico-legal material was compared to studies based both on clinical data and death certificates regarding head injuries and traumatic brain injuries [1-16], and studies on cranial fractures [17,18,20-24].

Validity

Our study was intended to provide an overview of cranial fractures caused by blunt force in a medico-legal material. We focused only on cranial fractures regardless of cause of death and the results naturally have to be interpreted with this in mind. The medico-legal autopsies in Denmark are performed on request of the police in cases of interest according to the legislation. This material is therefore characterized by comprising only a fraction of the deaths by accident or suicide, namely when there is doubt about the manner or cause of death. As a consequence of this the material reflects only a portion of the deaths with cranial fracture by blunt force in Denmark which, amongst others, is reflected in the distribution of the trauma type and age, e.g. there were only a few elderly in our material. BAC analysis was performed in most cases (75%), of which 40% were positive, while forensic toxicology analysis was performed in half of the cases, of which 20% tested positive. A selection bias is thus introduced by the police not requesting analysis in all cases.

Manner of death and trauma type

In some aspects our material reflects the sex and age distribution of head injuries in Denmark and other countries [4,6-12,18]. As others, we also found a proportional peak in case numbers in the young children, the young adults and middle aged, while an otherwise reported increase in the total number of elderly [4,6-11,18] was not seen. This is most likely explained by a decrease in deaths were medico-legal autopsy was deemed necessary for this age group. The sex ratio is in line with other studies, with a preponderance of males compared to females [1,2,4-16,18]. We noticed, however, a levelling out of the sex difference in old age which has been mentioned only in a few other studies [1,8]. This probably reflects the composition of the population in general at that age.

Our study shows a peak of cranial fractures caused by traffic accidents in the young adults which coincides with the incidence rate of head injury in other studies [5,6,8,10,11,15,25]. In our study the number of cranial fractures caused by accidental falls is noticeable in the very young and increases through the age ranges, peaking in the age range of 51- 60 years. This is partly comparable to some studies [3,18], although in other studies the incidence progresses further throughout the older age ranges (75+ years) [6-12,14,15], together with an increasing mortality rate for falls [15]. In the mentioned studies the increase in falls substitutes traffic accidents as the prominent trauma type for head injuries, which is not the case in our study reflecting the medico-legal material. Compared to other European countries and the US, a high share of head injuries in Scandinavia were caused by falls [6,9,13,14,16], but head injuries in Denmark are predominantly caused in traffic [2]. In studies about the methods used in homicides [26-30] and interpersonal violence in assaults, blunt force was used in 16-36% of the homicides and in most of the assaults [31]. The blunt violence was mostly aimed at the head, including the face both in adults [27,30-32] and children [33], mainly by blows and kicks [27,28], although some studies found [26,32], similar to our findings, that a variety of blunt objects were used in approximately half of the homicides. The age and sex distribution of the homicide cases in our study matched the distribution found in other studies with a comparable population [28,33], although we found a preponderance of male cases in the age range <12 years, a tendency which Myhre et al. [3] also found. Only a few suicide cases are represented in our material, but even so the age and sex distribution corresponded to other studies [34-36], although no elderly cases were found in our material. Blunt force as a suicide method (e.g. jumping from heights/in front of motorised vehicles/trains, traffic accident) is not very common internationally [34-36] and has been described as a "hard suicide method" [37]. The number of car driver suicides in our material suggests that this method might be more common than expected [38].

Alcohol and substance abuse

One third of the fall cases, 25% of the traffic cases and some of the homicide cases tested positive for alcohol. This has also been found in similar studies of traumatic deaths [25,39,40] and in studies on drugged driving [41]. A few of the cases in our study tested positive for illicit drugs which also corresponds to other studies [42,43]. Others [39,44] found that head injury severity for blunt trauma did not increase depending on alcohol abuse, while Ingebrigtsen et al. [9] found a tendency towards greater severity. A positive alcohol test is common in fall cases, but regarding ground level falls no increasing injury severity was found even though half the cases tested positive for alcohol [45]. Preuss et al. [46] found that nearly 70% of cases with falls down stairs tested positive for alcohol, which in our study was true for 50% of the cases.

External lesions

The greatest part of the cases sustained external lesions in the course of the trauma to the head, and often there were several lesions per case. It has been found by Yartsev et al. [47] that external lesions of the head may be fairly predictable of cranial fracture or intracranial injury with a positive predictive value of ~80%. In the same study [47] it was also found that bleeding from the auditory canal was highly predictive (95%) for basilar cranial fracture which is in concordance with our material. In our study also mono- or biocular hematomas seemed to be associated with fracture of the frontal cranial base. We also found several cases, distributed evenly across the age ranges, with no external lesions yet cranial fractures of varying severity. Lack of registration by the pathologist or healing of injuries in cases which initially survived could explain some of the absent injuries and instant death the absence of e.g., sugillations [48]. Also the biomechanical trauma circumstances, e.g., the size of impact area, the nature and surface of the impacting material/object are of significance for the causation of external injuries. We are not aware of studies that explicitly have focused on an absence of external injuries on the head despite the application of a substantial amount of force. Kremer et al. [49] found that over half of the included fall cases did not sustain lacerations, in a retrospective study systematically analysing the relation of skull fractures to the Hat Brim Line. However, in their study there was no mention of other external injuries. Hartshorne et al. [45] noted that internal head injuries often were more severe than predicted from the relatively minor external injuries, in an analysis about ground-level falls,.

Fractures of the neurocranium

Linear fractures of the neurocranium caused by blunt force are reported to be the most common cranial fracture in population studies [17], clinical studies [3,50], medico-legal studies [21] and experimental studies [19], which is in line with our study. Also the share of comminute fractures in our study corresponds to other studies [17,21], while there are fewer depressed fractures in our and LeCounts [21] material than in other studies [17,50]. This might be explained by the selected medico-legal material and possibly an increased chance of survival with a sustained localised depressed fracture compared to the other fracture types. Ring fractures are known to occur seldom [51,52].

Fractures of only the base are often the result of severe trauma [20,53]. In our material the fractures involved only the base in a third of the cases which is similar to other studies which found that this occurred in approximately 20% of the cases [17,54]. In contrast to this, Bauer [22] refers to several medico-legal studies which report fractures involving only the base in 60-70% of the cases. Others have found the combination of both basilar and vault involvement to be common, while involvement of only the vault occurs less often [21-23]. Jennett et al. [54] report in a clinical study that radiologically detected vault fractures occurred in 62% of the cases and found less common involvement of both the base and the vault (27%). This might be explained by radiologic difficulties in diagnosing fractures located in the cranial base, especially by traditional X-raying, which can result in minor cranial basal fractures not being diagnosed.

Intracranial lesions

The most frequent intracranial lesion was the subarachnoid haemorrhage followed by cerebral contusions. Similar results were found in a study based on emergency department admissions in which both subarachnoid haemorrhages and contusions were found in approximately

30% of the patients, with increasing incidence with increasing injury severity [15]. Kleiven et al. [6] basically reported the same proportions in a Swedish study, but it should be noted that cranial fractures occurred in only 14% of the overall head injury material in Sweden. In contrast, in an American study Freytag [55] found that 12% of the cases in a medico-legal material had suffered severe subarachnoid haemorrhages and nearly 89% lacerations and contusions. Freytag [55] also found a high frequency (63%) of subdural haemorrhages. Other studies [6,15,50,56] have also reported a higher frequency than we find, which amongst other things could be due to difficulties diagnosing the haemorrhages at the autopsy and also due to the selected medico-legal material in this study focusing only on cases with cranial fracture and not all head injuries. The frequency of the epidural haemorrhages is the same as in Kleiven et al.'s study [6], but less frequent than in the other studies [15,50,55]. Epidural haemorrhage is generally considered to be seldom [56], probably because fracture of the parietotemporal bones with subsequent rupture of the middle meningeal artery does not occur very often. To our knowledge no studies have reported an increased occurrence of epidural haemorrhages on either side of the head, although Kremer et al. [49] reported a side lateralization in cranial fractures induced by falls, which were mainly on the right side of the head, as opposed to fractures induced by blows, which were mainly located on the left side of the head. Such a lateralization of cranial fractures was not found in our study.

CONCLUSION

We report the summary statistics for cases with cranial fractures in a medicolegal material over the course of a 6-year period in Denmark. Our comprehensive data provide baseline characteristics of this forensically important group. Head injuries with cranial fracture are mainly seen in traffic related deaths, especially affecting the young adults (18-31 years). Traffic related deaths with cranial fracture constitute 37.5% of the medicolegally autopsied traffic related deaths in this period. Falls were also a prominent trauma type throughout every age range. A positive test for alcohol was common in ground level falls and falls down stairs, especially in the group of chronic alcohol abusers. This stresses the known vulnerabilities of this group and also the fatal consequences a fall from a limited height may have. Nearly every victim sustained external injuries varying from small excoriations to severe burns and comminution of the head. Mono- or biocular hematomas and bleeding from the auditory canal corresponded well to find of cranial fractures. The linear fractures were the most common cranial fractures and most of the fractures were, reflecting the medico-legal material, accompanied by moderate to severe intracranial injuries or/ and severe injuries of other organsystems resulting in the fatal outcome. Localised intracranial lesions: subarachnoid haemorrhages, contusions and cerebral haemorrhages were often found corresponding to the frontal, temporal and occipital lobe and the cerebellum. In half of the cases a uniform distribution over the cerebral hemispheres was found. The frequency of subdural and epidural haemorrhages was as expected in a medico-legal material, but the primarily right sided distribution of the epidural haemorrhages was surprising and needs further investigation. Future studies will especially focus on the causative relationship between trauma type, the resulting head impact and both cranial fracture and brain injuries.

REFERENCE LIST

[1] Jennett B. Epidemiology of head injury. Arch Dis Child 1998; 78(5): 403-6.

[2] Engberg AW, Teasdale T. Traumatic brain injury in Denmark 1979-1996. A national study of incidence and mortality. Eur J Epidemiol 2001; 17(5): 437-42.

[3] Myhre M, Grøgaard J, Dyb G, Sandvik L, Nordhov M. Traumatic head injury in infants and toddlers. Acta Pædiatrica 2007; 96: 1159-63.

[4] Engberg AW, Penninga EI, Teasdale TW.[Nordic accident classification system used in the Danish National Hospital Registration System to register causes of severe traumatic brain injury]. Ugeskr Læger 2007; 169(45): 3856-60.

[5] Sundstrøm T, Sollid S, Wester K.[Deaths from traumatic brain injury in the Nordic countries, 1987-2000]. Tidsskr Nor Lægeforen 2005; 125: 1310-2.

[6] Kleiven S, Peloso PM, Holst Hv. The epidemiology of head injuries in Sweden from 1987 to 2000. Inj Control Saf Prom 2003; 10(3): 173.

[7] Steudel WI, Cortbus F, Schwerdtfeger K. Epidemiology and prevention of fatal head injuries in Germany - trends and the impact of the reunification. Acta Neurochir (Wien) 2005; 147(3): 231-42.

[8] Tiret L, Hausherr E, Thicoipe M, Garros B, Maurette P, Castel JP, Hatton F. The Epidemiology of Head Trauma in Aquitaine (France), 1986: A Community-Based Study of Hospital Admissions and Deaths. Int J Epidemiol 1990; 19(1): 133-40.

[9] Ingebrigtsen Tor, Mortensen Kim, Bertil Romner. The Epidemiology of Hospital-Referred Head Injury in Northern Norway. Neuroepidemiology 1998; 17: 139-46.

[10] Sosin D, Sacks J, Smith S. Head-Injury Associated Deaths in the United States from 1979 to 1986. JAMA 1989; 262(16): 2251-5.

[11] Cohadon F, Richer E, Castel J. Head injuries: incidence and outcome. J Neurol Sci 1991; 103: S27-S31.

[12] Bruns J, Hauser WA. The Epidemiology of Traumatic Brain Injury: A Review. Epilepsia 2003; 44(s10): 2-10.

[13] Tagliaferri F, Compagnone C, Korsic M, Servadei F, Kraus J. A systematic review of brain injury epidemiology in Europe. Acta Neurochir (Wien) 2006; 148(3): 255-68.

[14] Adekoya N, Thurman D, White D, Webb K. Surveillance for Traumatic Brain Injury Deaths - United States, 1989-1998. CDC Surveillance Summaries 2002; 51 (SS10)MMWR December 6, 2002: 1-16.

[15] Masson F, Thicoipe M, Aye P, Mokni T, Senjean P, Schmitt V et al. Epidemiology of Severe Brain Injuries: A Prospective Population-Based Study. J Trauma 2001; 51: 481-9.

[16] Murray G, Teasdale G, Braakman R, Cohadon F, Dearden M, et al. The European Brain Injury Consortium Survey of Head Injuries. Acta Neruochir (Wien) 1999; 1999(141): 223-36.

[17] Nelson E, Melton J3, Annegers J, Laws ER, Offord K. Incidence of skull fractures in Olmsted County, Minnesota. Neurosurgery 1984; 15(3): 318-24.

[18] Johnstone A, Zuberi S, Scobie W. Skull fractures in children: a population study. J Accid Emerg Med 1996; 13: 386-9.

[19] Gurdjian E. Deformation Studies Of The Skull: Mechanisms Of Skull Fracture. Impact Head Injury - Mechanistic, Clinical and Preventive Correlations. Springfield, Illinois: Charles C Thomas. 1975; 113-38.

[20] Rawling LB. Fractures Of The Skull. The Surgery Of The Skull And Brain. London: Oxford Medical Publications. 1912; 68.

[21] LeCount ER, Apfelbach C. Pathologic anatomy of Traumatic Fractures of Cranial Bones and Concomitant Injuries. JAMA 1920; 74: 501-11.

[22] Bauer KH. Der Bruch der Schädelbasis. Verhandlungen Der Deutschen Gesellschaft Für Chirurgie. Archiv Für Klinische Chirurgie 196, 460. 1939. Berlin, Julius Springer.

[23] Vance B. Fractures of the Skull - Complications and Causes of Death: A Review of 512 Necropsies and of 61 Cases studied Clinically. Arch Surg 1927; 14: 1023-92.

[24] Gurdjian ES, Webster JE, Lissner HR. The Mechanism of Skull Fracture. Radiology 1950; 54: 313-39.

[25] Törö K, Hubay M, Sótonyi P, Keller E. Fatal traffic injuries among pedestrians, bicyclists and motor vehicle occupants. Forensic Sci Int 2005; 151(2-3): 151-6.

[26] Saint-Martin P, Bouyssy M, Bathellier S, Sarraj S, O'Byrne P. Homicide in Tours (Indre-et-Loire, France): A four-year review. J Clin Forensic Med 2006; 13(6-8): 331-4.
[27] Henderson JP, Morgan SE, Patel F, Tiplady ME. Patterns of non-firearm homicide. J Clin Forensic Med 2005; 12(3): 128-32.
[28] Rogde S, Hougen H, Poulsen K. Homicide by Blunt Force in 2 Scandinavian Capitals. Am J Forensic Med Pathol 2003; 24(3): 288-91.
[29] Ericsson A, Thiblin I. Injuries inflicted on homicide victims - A longitudinal victiminologic study of lethal violence. Forensic Sci Int 2002; 130: 133-9.
[30] Ambade VN, Godbole HV. Comparison of wound patterns in homicide by sharp and blunt force. Forensic Sci Int 2006; 156(2-3): 166-70.
[31] Brink O, Vesterby A, Jensen Jr. Pattern of injuries due to interpersonal violence. Injury 1998; 29(9): 705-9.
[32] Murphy G. "Beaten to death" - An Autopsy Series of Homicidal Blunt Force Injuries. Am J Forensic Med Pathol 1991; 12(2): 98-101.
[33] Christiansen S, Rollman D, Leth P, Thomsen J. Children as victim of homicide 1975-2005. Ugeskr Læger 2007; 169(47): 4070-4.
[34] Burns A, Goodall E, Moore T. A study of suicides in Londonderry, Northern Ireland, for the year period spanning 2000-2005. J Forensic Leg Med 2008; 15(3): 148-57.
[35] J.P.Henderson, Mellin C, Patel F. Suicide - A statistical analysis by age, sex and method. J Clin Forensic Med 2005; 12(6): 305-9.
[36] Rogde S, Hougen HP, Poulsen K. Suicides in two Scandinavian capitals - A comparative study. Forensic Sci Int 1996; 80(3): 211-9.
[37] Schmidt P, Müller R, Dettmeyer R, Madea B. Suicide in children, adolescents and young adults. Forensic Sci Int 2002; 127(3): 161-7.
[38] Murray D, de Leo D. Suicidal Behavior by Motor Vehicle Collision. Traffic Inj Prev 2007; 8(3): 244-7.
[39] Demetriades D, Gkiokas G, Velmahos GC, Brown C, Murray J, Noguchi T. Alcohol and illicit drugs in traumatic deaths: Prevalence and association with type and severity of injuries. J Am Coll Surg 2004; 199(5): 687-92.
[40] Tsai V, Anderson C, Vaca F. Young Female Drivers in Fatal Crashes: Recent Trends, 1995-2004. Traffic Inj Prev 2008; 9: 65-9.
[41] Christophersen AS, Ceder G, Kristinsson J, Lillsunde P, Steentoft A. Drugged driving in the Nordic countries-: a comparative study between five countries. Forensic Sci Int 1999; 106(3): 173-90.
[42] Bernhoft IM, Steentoft A, Johansen SS, Klitgaard NA, Larsen LB, Hansen LB. Drugs in injured drivers in Denmark. Forensic Sci Int 2005; 150(2-3): 181-9.
[43] Behrensdorff I, Steentoft A. Medicinal and illegal drugs among Danish car drivers. Acc Anal Prev 2003; 35(6): 851-60.
[44] Edna T. Alcohol influence and head injury. Acta Chir Scand 1982; 148: -209.
[45] Hartshorne N, Harruff R, Alvord EJr. Fatal Head Injuries in Ground-Level Falls. Am J Forensic Med Pathol 1997; 18(3): 258-64.
[46] Preuß J, Padosch SA, Dettmeyer R, Driever F, Lignitz E, Madea B. Injuries in fatal cases of falls downstairs. Forensic Sci Int 2004; 141(2-3): 121-6.
[47] Yartsev A, Langlois NEI. A comparison of external and internal injuries within an autopsy series. Med Sci Law 2008; 48(1): 51-6.
[48] Vanezis P. Interpreting bruises at necropsy. J Clin Pathol 2001; 54(5): 348-55.
[49] Kremer C, Racette S, Dionne C-A, Sauvageau A. Discrimination of Falls and Blows in Blunt Head Trauma: Systematic Study of the Hat Brim Line Rule in Relation to Skull Fractures. J Forensic Sci 2008; 53(3): 716-9.
[50] Macpherson B, Macpherson P, Jennett B. CT Evidence of Intracranial Contusion and Haematoma in Relation to the Presence, Site and Type of Skull Fracture. Clin Radiol 1990; 42: 321-6.
[51] Voigt GE, Skold G. Ring fractures of the base of the skull. J Trauma 1974; 14(6): 494-505.
[52] Gan YC, Charkravarty D, Flint G. Ring fracture of the skull base: case report and review of the literature. Bri J Neurosurg 2002; 16(3): 300-3.
[53] Rowbotham GF. The mechanisms of injuries of the head. Acute Injuries Of The Head. Edinburgh and London: E.& S.Livingstone Ltd. 1964; 56-69.
[54] Jennett B, Teasdale G, Galbraith S, Pickard J, Grant H, Braakman R et al. Severe head injuries in three countries. J Neurol Neurosurg and Psychiatry 1977; 40: 291-8.
[55] Freytag E. Autopsy Findings in Head Injuries from Blunt Forces - Statistical Evaluation of 1367 Cases. Arch Pathol 1963; 75: 402-13.
[56] Tallon J, Ackroyd-Stolarz S, Karim S, Clarke D. The epidemiology of surgically treated acute subdural and epidural hematomas in patients with head injuries: a population-based study. Can J Surg 2008; 51(5): 339-45.

Cranial fracture characteristics and their impact regions in blunt trauma types

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Abstract

Cranial fractures caused by blunt trauma are a common occurrence in forensic pathology. In this study we aimed at improving our understanding of cranial fractures based on a contemporary medico-legal autopsy material and thereby provide up-to-date knowledge for basic forensic interpretations (including post-mortem radiology), preventive measures and biomechanical studies. The study is based on 428 cases derived from medico-legal autopsies performed in Denmark in a 6-year period (1999-2004). The male:female ratio was 3:1. Autopsy findings regarding the cranial fractures, the associated scalp injuries, the manner of death, cause of death and the trauma type were registered by reviewing the autopsy reports. We characterized the cranial fractures by focusing on the cranial fractures morphology, the scalp injuries and the trauma type. The fractures were classified as either linear fractures, depressed, multiple, ring, comminute and combination. Further subdivisions pertaining to orientation and anatomical localisation were also noted. The scalp injuries were anatomically classified by dividing the scalp into six general regions. Injuries could involve one or more regions. Accidents were the most common manner of death (n=372). The cranial fractures were mainly linear (~60%) or comminute, involving the cranial base in 90% of the cases. Regardless of trauma type, the study showed general trends regarding an association between occipital impacts and longitudinal linear fractures (45/69; 65% CI 53%-76%) and lateral (temporal, parietal, or both) impacts and transverse linear fractures (52/80; 65% CI 54%-75%). In addition, we noted that depressed fractures most often were caused by lateral impacts (15/19, 78% CI 54%-94%). In traffic accidents the most common impact regions were the lateral and frontal regions, inducing mainly linear and other fracture types in car occupants and pedestrians. The most common impact region in ground level falls was the occiput inducing linear fractures. With increasing height the lateral regions became more involved. The impacts in the homicide and accident cases occurred mainly in the lateral regions, inducing both linear and other fracture types. In the homicides the victims often sustained several injuries involving a large area of the scalp. We consider the results useful both in the medico-legal setting, including post mortem radiology, when evaluating the complex process leading to cranial fractures. Furthermore the data may provide information for developing biomechanical head injury models or protective measures.

Keywords: Cranial fracture, Blunt trauma, Trauma type, Impact region

Introduction:

Already Hippocrates knew that the appearance of scalp injuries and cranial fractures could be of importance for determining the characteristics of impact injuries [1]. Knowledge of the traumatic injuries associated with different trauma types forms the basis for interpreting traumatic forces in blunt head injuries, both as regards cranial fractures as well as intracranial injuries. The anatomic localisation and appearance of a fracture may provide information about a possible site of impact and thereby important information about force directions and associated intracranial injuries [2;3].

Most of today's knowledge about the cranial fractures causative mechanisms is from studies carried out in the beginning and middle of the last century [4-9]. Since then many studies have focused on specific trauma mechanisms and types and the concomitant injuries [10-34], e.g. for developing preventive and protective measures, with only very few studies looking at cranial fractures and the trauma type in general [33;35;36]. In the last decades, especially biomechanical studies have been carried out to develop cranial models for analyzing head injury [16;37-44]. To our knowledge there are no recent studies linking the anatomic localisation, orientation and extent of cranial fractures with the impact regions for different trauma types.

In this study we therefore wanted to characterize cranial fractures caused by blunt force by focusing on the cranial fractures, the scalp injuries and the trauma type. The overall aim was to improve our understanding of cranial fractures based on a contemporary medico-legal autopsy material and thereby provide up-to-date knowledge for basic forensic interpretations (including post mortem radiology), preventive measures and biomechanical studies. To achieve this, we related observed scalp injuries to the cranial fractures on a case-by-case basis and hence estimated the scalp injuries as area of impact. We then compared the fractures and the impact patterns with trauma type, with a special focus on traffic accidents and falls.

Material and Methods:

This study is based upon medico-legal autopsies performed at the three forensic institutes in Denmark; Copenhagen, Århus and Odense. A total of 8682 autopsies were performed at the institutes during a 6-year period (1999-2004). The cases were selected by using databases at the institutes. All cases with fracture of the neurocranium caused by blunt trauma were selected. This resulted in a total of 428 cases equivalent to 5% of the total sum of autopsies in the period. Cases with fractures of only the facial skeleton, intracranial injuries without cranial fractures, and cases involving penetrating trauma (sharp force and fire arms) were excluded. The material comprised 330 males (age span: 0 - 93 years; median: 40 years) and 98 females (age span: 0 - 89 years; median: 59 years), with a male-female ratio of 3:1 (see figure 1).

The autopsy findings regarding the cranial fractures, the associated scalp injuries, the manner of death, cause of death and the trauma type were registered by reviewing the autopsy reports. The trauma type was classified as either traffic accidents (with further subdivisions); falls (with further subdivisions depending on height); hit/struck by blunt object by accident or during the course of interpersonal violence or homicide; or as other.

The fractures were classified as either linear fractures or other fracture types, the latter further subdivided into depressed, multiple, ring, comminute, combination and inconclusive (modified after Gurdjian [45]). Further subdivisions pertaining to orientation were also used [2]. In addition, the fractures were sorted according to their anatomic localisation: base and vault; base or vault. The fractures situated in the base with a presumed related impact area were classified according to their morphological appearance (following the various fracture types described above) and are not discussed in detail.

The scalp injuries were anatomically classified by dividing the scalp into six general regions: frontal, left and right temporal, left and right parietal and occipital (generally following the vault bones). Injuries could be distributed over a smaller or larger area, thereby involving one or more regions and therefore the extent of the single or group of injuries was classified as involving one region or neighbouring regions. Involvement of more than three regions, opposite regions or involvement of the whole scalp was summarized as other regional combinations. Except in the subdivisions pertinent to injuries involving only one region, the temporal and parietal regions were combined and simply denoted as lateral regions.

For every case the relation of the scalp injuries to the cranial fractures was analyzed and if possible subsequently matched in order to estimate the area of impact. If the fracture observed at the autopsy was linear it was estimated, based on earlier findings [3;5;6], that the corresponding impact had occurred anatomically nearby to the linear fracture. It was assumed that the linear fracture either reached the area of impact, crossed the area of impact or ended near the area of impact [3;5;6]. All the other fracture types, except from the ring fractures, were characterized by local bone failure corresponding directly to the area of impact facilitating the matching. If the fracture anatomically was located only in the base, it was estimated, based on earlier findings [4] that a possible related impact could have occurred at base level or on the vault. It is well known that other impacts, e.g. facial impacts or fall on the buttocks, cause basilar fractures [2;46], but to minimise interpretational bias we chose to classify impacts which could not, with a reasonable amount of certainty, be related to fractures as "non relatable" (and this included facial injuries). Some cases were characterized by having several fractures apparently independent of each other, e.g. a longitudinally oriented linear fracture in the occipital bone and transversely oriented linear fractures in the petrous parts of both temporal bones. Gurdjian et al. [6] has shown that additional fractures can occur at a distance away from the impact. These cases were classified depending on whether a scalp injury could be associated directly to the presumed primary impact area and fracture. If this was not possible the cases were classified as inconclusive. In a few cases the fracture description in the autopsy reports was unclear and these cases were also classified as inconclusive.

Results:

The majority of the individuals died due to accidents, primarily traffic accidents and falls (table 1). The cause of death was craniocerebral injuries in 55% of the cases and in nearly half of the remaining cases poly-trauma, i.e. the craniocerebral injuries were combined with substantial injuries of other organ systems. There was no difference in the cranial fracture characteristics of these two groups. In a few cases the cause of death was undetermined.

Fracture types

The fractures of the neurocranium varied from single, small fractures in the eye loft of the frontal bone (e.g. car driver involved in a frontal collision) to comminute fractures of the cranium (e.g. fall from a height of 5 metres). Table 2 shows the overall distribution of the fracture types and their anatomic localisation. The linear fractures comprised ~60% of the total material with varying orientations in the cranium: longitudinal; transverse; or oblique or a combination of these. The other fracture types ranged from involving small areas of the vault, e.g. a local depressed fracture, to involving large areas as in massive comminute fractures. Some of these fractures were combinations of the fracture groups (n=42), e.g. depressed fractures combined with multiple fractures or linear fractures, and were therefore grouped separately. The overall anatomical localisation of the fractures was the vault and base and secondly only the base, resulting in a basilar involvement in approximately 90% of all the cases. Sixteen of the transversely oriented linear fractures located in the base (16/45) were described as "hinge fractures" in the autopsy reports. Most of the linear vault fractures had extensions into the base and there were relatively few fractures involving only the vault. The linear fractures in the group of vault fractures were characterized by being orientated in different planes, e.g. horizontally in the vault; in a coronal plane involving the vertex; or following the sutures with diastases. In eleven cases we were not able to clearly classify the fracture type (inconclusive).

Scalp injuries

Almost all cases (398/428) presented one or more scalp injuries in the different regions of the scalp. The scalp injuries consisted of contusion wounds, excoriations, sugillations/subgaleal haematomas and other injuries (e.g.

burns). The six regions comprised 722 single or groups of injuries (e.g., a sugillation with a central excoriation) (see table 3). Figure 1 shows how many and which injuries in each region were related to a cranial fracture.

Impact and fracture type

Table 4 shows how the injuries involving one or more (neighbouring) regions are related to the cranial fracture types. In 50 cases the scalp injuries could not be associated with fractures, and in 29 cases scalp injuries had not been reported in the autopsy reports. (Eleven of these 29 cases had been hospitalized and treated prior to death, and six of these survived more than three days, which could have resulted in healing of minor scalp injuries prior to the autopsy.) The cases with no injuries or in which injuries were not relatable to the fractures, as well as the fractures classified inconclusive, were disregarded in the subsequent analysis.

The area in which an impact caused a fracture was estimated by relating the scalp injuries to the cranial fractures. In table 4 it is seen that the longitudinal linear fractures mainly were induced by impacts in the occipital and frontal region (53/69), while the transverse linear fractures were caused by fracture related impacts in the parietal, temporal and lateral regions (52/80), in some cases also in combination with the frontal or occipital region (16/52). The linear fractures oriented obliquely or in multiple directions were predominantly caused by fracture related impacts in the border area of regions, especially in the frontal or occipital area combined with the lateral regions (40/51). When impacts caused injuries extending beyond one region, i.e. into neighbouring regions, these injuries always included the lateral regions generally resulting in equally many other fracture types (48/108) and linear fractures (60/108), mostly oriented transverse (n=36) or oblique (n=19).

The other fracture types, except from the ring fractures, were characterized by being closely related to the impact area. Table 4 shows that the depressed fractures were typically located in the parietal, temporal and lateral and/or frontal regions (15/19), affecting mostly the temporal or parietal bones. The comminute fractures were caused in impacts involving one or neighbouring regions as well as in impacts which included several regions or impacts which were grouped as other regional combinations, e.g. severe scalp laceration, partial amputation of the head, severe burns etc. The 15 cases with ring fracture were all complete (except one) and could not be associated with a specific lesion pattern. In six of these cases no scalp injuries/impacts were found, while the remaining injuries were distributed evenly between the frontal, parietal, temporal and occipital region.

Fractures, impacts and trauma type

The different trauma types were characterized by fracture related impacts in different regions and different fracture types. These data are presented in table 5 and 6. Table 5 shows the direct association between the linear fractures, their impact region and trauma type. Table 6 shows the same for the other fracture types. The cases with no injuries, not relatable injuries and inconclusive fractures as also the spider web fractures were not included in the tables.

Table 5 and 6 show that car drivers sustained linear and other fracture types in an equal number (n=24 and n=29 cases, respectively), and except in one case the impact area never included the occiput. Comminute fractures were the single most common fracture type for car drivers (16/52), in keeping with the high energy nature of many collisions, followed by transverse linear fractures (10/52), due to impacts in the parietal, temporal, lateral and/or frontal regions. Conversely, transverse linear fractures were not found in any of the front seat or back seat car occupants. Linear fractures were the most common fracture types for bicycle riders (23/33) and amongst these the most common were transverse fractures due to parietal, temporal, lateral and/or frontal impacts (9/23). One third of bicycle riders sustained other fracture types (table 6), e.g. one ring fracture, suggesting greater energy. There was no evident resemblance regarding the localisation of fracture related impacts in falls from a bicycle versus ground level or 2-3 metre falls. There was seldom information whether bicycle riders had used protective helmets. In the few cases were this was the case the lesion or fracture pattern did not differ from the unprotected group. Like the bicycle riders, the group of pedestrians (44) mainly sustained fracture related impacts in the parietal, temporal, lateral and/or frontal regions of the head (29/44). Occipital impacts in traffic accidents were mostly sustained by bicyclists (8/33) and pedestrians (9/44) inducing longitudinally oriented linear fractures in eleven of these cases. Overall, traffic accidents had a high proportion of comminute fractures (47/194). Not unexpectedly, this proportion was the highest for the traffic accident group denoted “Other” which mainly included train and aircraft accidents (11/21).

Cranial fractures due to falls presented a very characteristic impact and fracture pattern in that the occipital region, at times in combination with the lateral region, was involved in 49% (51/104) of these cases. This was most apparent in the subgroup of ground level falls (22/36) and falls from 2-3 metres (13/28). Table 5 shows that fracture related impact in the occipital and frontal region in ground level falls induced longitudinally oriented linear fractures in 89% (17/19) of the cases. Not surprisingly, an increase in the fall height seemed to cause a decrease in the linear fractures. Linear fractures comprised almost 92% (33/36) of all fractures in ground level falls, and this was reduced to approximately 38% (5/13) in falls from above 5 metres. With an increasing fall height, a more general involvement of the lateral region occurred more often. In contrast to the traffic accidents, only 5% (5/104) sustained comminute fractures. In three ground level falls the victim struck an object on the floor which caused the other fracture types (3/23). In 21 cases contre-coup fractures in the eye loft were registered at the autopsy, associated with impact in the occipital region (data not shown).

Accidents with blunt objects (n=13) happened in various settings and with various objects. The fracture related impacts (n=13) (see table 5 and 6) were located in the parietal, temporal, lateral and/or frontal regions (9/13) inducing mainly linear transverse fractures (n=4) and other fracture types (n=4). There were two depressed fractures.

The homicides (n=26) constituted four falls which happened in the course of a struggle, four assaults with blows, kicks or trampling on the victims head and eighteen assaults with a variety of different blunt objects. All of the fall cases sustained fracture related impacts in the occipital region with longitudinally oriented linear fractures (data not specified). In the remaining cases with fracture related impacts (n=20) (table 5 and 6) the lateral and/or the frontal or occipital regions were involved in 70% (14/20) of the cases. Also fracture related impacts in "other regional combinations" were common (30%, n=6/20), e.g. injuries in both parietal, one temporal and the occipital region. Involvement of only one region did not occur often (4/20). The other fracture types constituted more than half of the fractures (11/20) suggesting that both a substantial amount of force was used in these homicide cases and/or repeated impacts towards the same area.

Overall, regardless of trauma types, our study clearly shows some general trends regarding an association between occipital impacts and longitudinal linear fractures (45/69; 65% CI 53%-76%) and lateral (temporal, parietal, or both) impacts and transverse linear fractures (52/80; 65% CI 54%-75%). Furthermore, we note that regarding depressed fractures these were most often caused by lateral impacts (15/19, 78% CI 54%-94%). More diffuse patterns were evidenced by linear fractures with an oblique orientation, and not surprisingly for comminute fractures, where impacts mostly were classified as “other combinations” (21/47, 45% CI 31%-59%).

Discussion

The main focus of this retrospective study was to explore the relation between impacts to the cranium and subsequent cranial fractures for different types of trauma. Central to this was the estimation of the area of impact based upon the association between the cranial fracture type and the external injuries as observed at autopsy. Realizing the complicated biomechanical process leading from an impact to a cranial fracture, we performed this estimation conservatively, so that any cases where the recording of either injuries or fractures was uncertain or seemed ambiguous were excluded. In 10% of our cases we were not able to relate the registered injuries to the fractures.

When we reviewed the cases, we also noted that scalp injuries had not been found in several cases, and this did not seem to depend on the energy level of the trauma or the associated fracture severity, e.g. comminute fractures in severe high energy traffic traumas or linear fractures in ground level falls on a tile floor. There could be various reasons for injuries not being present or not being recorded at autopsy: minute injuries not registered in the autopsy report; injuries overlooked by the pathologist if vital reaction was missing; preventive measures in the car interior (airbags) or various other trauma mechanisms than direct impact, e.g. hyperextension. The latter could also be true for the cases where we were not able to relate injuries with fractures. The lack of or minuteness of scalp injuries combined with severe cranial fracture or injuries of the central nervous system has been described earlier [8;10;32;47]. Also Kremer et al. [48] found that over half of the included fall cases did not sustain lacerations, in a retrospective study systematically analysing the relation of skull fractures to the Hat Brim Line. However, in their study there was no mention of other external injuries. Nonetheless other studies have shown that scalp injuries are more often associated with severe head injury or cranial fracture than not [38;49]. In our study there were 10 cases with only facial injuries, which were classified as not being directly associated to the fractures, but it is possible that the facial impacts may have resulted in basilar fractures, as this is a well known trauma mechanism [4;36;46;47]. In a future study it may be of interest to investigate trauma mechanisms with indirect forces to the head more closely.

Our results, concerning the cases in which an association between scalp injuries as regards impact and subsequent cranial fracture could be made, confirmed earlier findings [4-7]. The fracture related impacts in the lateral regions resulted mainly in transverse linear fractures, impacts in frontal and occipital regions resulted mainly in longitudinal fractures and impacts in the lateral parts of a single region resulted mainly in oblique fractures, which has also been found by others [4-6]. However, exceptions to these generalizations exist, especially regarding basilar fractures only, which is indicated by both our results and the results of others [50]. Gurdjian et al.[6] demonstrated that linear fractures are caused by impacts on broad, flat surfaces. This was probably also the case for the origin of the linear fractures in our material. The other fracture types were closely related to impacts and were, except from the ring fractures, characterized by failure of the bone in relation to the impact. Gurdjian et al. [6] showed that failure of the bone is the result of impacts with a high enough energy and/or velocity level, e.g. either in a small area resulting in a depressed fracture, or in a larger area resulting in a multiple or comminute fracture. It is also known that very little additional force is needed to induce severe fractures with local bone failure in an already (linearly) fractured cranium [6;51].The ring fractures in our material were, except from one ground level fall, caused in traffic and in our material the localisation of the scalp injuries varied. In 70% of these cases impact injuries were either not found or could not be related directly. This may support the assumption of indirect force e.g. hyperextension as ring fractures are often associated with high energy traumas [52;53] and are caused by various trauma mechanisms [2;53].

We found that the fracture related impact in linear fractures with involvement of both base and vault often was sustained in the vault, resulting in a linear fracture extending into the base, which also has been noted by others [6;7;54]. The orientation of the linear fractures in the base and vault mainly corresponded to the weak and strong areas of the cranium confirming earlier findings [4;6]. Fractures located only in the vault occurred only in a few cases, which was in concordance with Vance [7]. This is probably also a reflection of the selection of our material: namely that all our cases sustained fatal injuries. Presumably a clinical study would comprise more vault fractures. The other fracture types were, except from comminute and ring fractures, often the result of a trauma in a rather limited area with subsequent failure of the bone and were therefore mostly located in the base and/or vault.

The linear and the other fracture types were distributed 3:2 in our material. In other studies [35;45;55] the share of linear fractures was largely the same. In our material the fracture related impacts involving only one region produced linear fractures in two thirds of the cases. As soon as the impacts involved several regions the opposite was the case, as other fracture types were produced in two thirds of the cases. This suggests a higher velocity and/or energy level in these cases possibly combined with a biomechanically complicated sequence of impacts to the head. Falls resulted in 70% of the fracture related impacts in one region while traffic traumas resulted in 40% of these. More than half (60%) of the fracture related impacts in several or neighbouring regions were caused in traffic traumas while only 30% were caused in falls. Individuals hit or struck by blunt objects in the group of homicides, mostly (80%) sustained fracture related impacts involving neighbouring or several regions classified as "other regional combinations". Also the share of "other fracture types" was high. Both the energy and velocity in these types of trauma is not as high as in e.g. traffic accidents, but the amount of scalp injuries and severe fracture types caused per case in homicides by blunt object was higher than in the other trauma types. This may suggest that the homicide cases often receive several blows resulting in severe fractures.

In keeping with the findings of others [12;38] we found that car occupants mainly sustained fracture related impacts in the frontal and lateral regions inducing slightly more other fracture types than linear indicating a high energy and velocity level in these traumas. Cyclists and pedestrians in our material sustained equally many other fracture types and linear fractures (oriented longitudinally and transversely) resulting from fracture related impacts in the lateral and occipital regions. Similar results regarding pedestrians and bicyclists were found by others [16;20].

In ground level falls we found the largest amount of mainly linear fractures oriented longitudinally caused by fracture related occipital impacts; the other fracture types in this height were scarce. Others [29;30;32] also found that the most common impact region was the occiput followed by the lateral regions [30] or frontal region in ground level falls [32] as well as in falls down stairs [30]. The share of other fracture types rose as soon as the height was over 3 metres with impacts more often involving several regions and a decrease of occipital impacts. Cummins et al. [28] found a marked involvement of impacts in the frontal region with increasing height, which did not seem to be the case in our study. The increased impacts in several regions in heights over 3 metres might be explained by increased movement of the body during the fall and prior to impact [56]. Contre-coup fractures were found in 16% of the falls which is similar to other studies [57;58]. Further studies are needed to establish the frequency and pathology of contre-coup fractures in falls.

The accidents with a blunt object resulted in nearly equally many other fracture types and linear fractures, typically transversely oriented. In the accidents the impact regions were mostly the lateral regions followed by the frontal regions. In the homicides the frontal or occipital region was only involved in a few cases, mainly in combination with other regions, suggesting that homicidal blunt force to the head is aimed mostly towards the lateral regions of the head. We noted that the external injuries often involved several regions, i.e. there were several external injuries over a large area. Kremer et al.[48] found similar results with a higher number of lacerations in blows compared to falls. They also found a predominance of cranial fractures located on the right side in falls and on the left side in homicides. In our study we did not analyze whether a side lateralization existed. In a clinical study about interpersonal violence Brink et al. [59] report that injuries mostly occur in the face, the lateral sides of the head and more seldom in the occiput. However, it must be assumed that the injury pattern in a homicide differs from assaults without homicidal intentions, but it seems plausible that mainly the lateral sides or the occiput are exposed in homicides, e.g. when the victim is lying down. Also in both in homicides and accidents it is possible that the victim turns the lateral side of the head towards the causative object.

The biomechanical process from an impact leading to a cranial fracture is complicated and various factors (e.g. velocity of object/individual; mass; impact area and surface) have to be considered in order to evaluate the sustained external, cranial and also intracranial injuries. Our study has basically validated earlier studies, especially the seminal studies by Rawling and Gurdjian et al. [4-6], regarding the associations between impact area and subsequent cranial fracture. In our study we further analysed this by adding the trauma type as a parameter. As such, our data reflect the spectrum of cranial fractures in modern forensic autopsy material. Our study may thus also point to some difficulties in terms of interpreting autopsy findings in these cases. For example, although we were able to relate scalp injuries to cranial fractures in most of our cases (90%), we also made note of the fact that there often were many more scalp injuries per case; indeed we initially found that approximately 48% of all scalp injuries could not be directly related to any cranial fractures. Probably most external injuries are associated with circumstances connected with the trauma type, but it does mean that when cranial fractures are present there must be a thorough observation and registration of all external injuries, and estimation of impacts must be carried out by carefully comparing the injuries with the fracture pattern. A prediction of which impacts may have caused a fracture is thus almost impossible based solely on an external examination.

Furthermore, our results show a very common involvement of the cranial base. This may have implications for the use of CT-scanning as a diagnostic tool in forensic pathology, as earlier studies [60;61] have shown that the CT scan based diagnosis of fractures in the cranial base may be difficult. In a previous study [62], we found that various CT visualisation protocols may alleviate this problem, but that differentiation between, e.g. a fall on the back of the head or a blow to the back of the head, is difficult and still necessitates an autopsy, combined with such basic knowledge about impacts, cranial fractures and trauma types as presented here.

Conclusion:

The results of this retrospective study have supported earlier findings regarding the relation between fracture related head impacts and the characteristics of a fracture. In addition to this, we were also able to relate the fracture related impacts to different common trauma types in a modern forensic autopsy material.
Regardless of trauma types, the study showed general trends regarding an association between occipital impacts and longitudinal linear fractures (45/69; 65% CI 53%-76%) and lateral (temporal, parietal, or both) impacts and transverse linear fractures (52/80; 65% CI 54%-75%). In addition, we noted that depressed fractures most often were caused by lateral impacts (15/19, 78% CI 54%-94%).
Overall, in traffic accidents the most common impact regions were the lateral and frontal regions. In car occupants and pedestrians this was associated with equally many linear fractures and other fracture types. In bicyclists the linear fractures occurred in two-thirds of the cases. Fractures in fall cases were mainly linear and in ground level falls the most common impact region was the occiput. With increasing height the lateral regions became more involved. The cases with accidental striking of with a blunt object or compression sustained most of their impacts in the lateral and frontal region with equally many linear and other fracture types. The impacts in the homicide cases

occurred in the lateral regions, often involving several regions inducing both linear and other fracture types. This may suggest that the victims received several impacts to the head. The induced other fracture types were characterized by a large number of fracture combinations.

We consider the results useful both in the medico-legal setting, including post mortem radiology, when evaluating the complex process leading to cranial fractures. Furthermore the data may provide information for developing biomechanical head injury models or protective measures.

Reference List

(1) Panourias I, Skiadas P, Sakas D, Marketos S: Hippocrates: A Pioneer in the Treatment of Head Injuries. Neurosurgery 2005; 57(1):181-189.

(2) Krantz KPG, Löwenhielm CGP: Head and Neck Injuries. Acta Neurochirurgica 1986; Suppl. 36:47-50.

(3) Hooper K: Injuries of the skull; Patterns of Acute Head Injury. 1969, pp 21-30.

(4) Rawling LB: Fractures Of The Skull; The Surgery Of The Skull And Brain. London, Oxford Medical Publications, 1912, p 68.

(5) Gurdjian ES, Webster JE, Lissner HR: The Mechanism of Skull Fracture. Radiology 1950; 54:313-339.

(6) Gurdjian ES, Webster JE, Lissner HR: Observations on Prediction of Fracture Site in Head Injury. Radiology 1953; 60(2):226-235.

(7) Vance B: Fractures of the Skull - Complications and Causes of Death: A Review of 512 Necropsies and of 61 Cases studied Clinically. Archives of Surgery 1927; 14:1023-1092.

(8) LeCount ER, Apfelbach C: Pathologic anatomy of Traumatic Fractures of Cranial Bones and Concomitant Injuries. Journal of the American Medical Association 1920; 74:501-511.

(9) Freytag E: Autopsy Findings in Head Injuries from Blunt Forces - Statistical Evaluation of 1367 Cases. Archives of Pathology 1963; 75:402-413.

(10) Menon A, Pai VK, Rajeev A: Pattern of fatal head injuries due to vehicular accidents in Mangalore. Journal of Forensic and Legal Medicine 2008; 15(2):75-77.

(11) Zentner J, Franken H, Löbbeke G: Head injuries from bicycle accidents. Clinical Neurology and Neurosurgery 1996; 98:281-285.

(12) Yavuz MSM, Asirdizer MM, Cetin GM, Gunay Balci YM, Altinkok MM: The Correlation Between Skull Fractures and Intracranial Lesions Due To Traffic Accidents.[Article]. American Journal of Forensic Medicine & Pathology 2003; 24(4):339-345.

(13) Törö K, Hubay M, Sótonyi P, Keller E: Fatal traffic injuries among pedestrians, bicyclists and motor vehicle occupants. Forensic Science International 2005; 151(2-3):151-156.

(14) Törö K, Szlávik N, Mèszáros Á, Dunay G, Soós M, Keller É: Jumping and falling death in children, adolescents, and young adults. Journal of Clinical Forensic Medicine 2006; 13:129-134.

(15) Hitosugi M, Takatsu A, Shigeta A: Injuries of Motorcyclists and Bicyclists Examined at Autopsy. The American Journal of Forensic Medicine and Pathology 1999; 20(3):251-255.

(16) Depreitere B, Van Lierde C, Maene S, et al: Bicycle-related head injury: a study of 86 cases. Accident Analysis and Prevention 2004; 36(4):561-567.

(17) Demetriades D, Murray J, Martin M, Velmahos G, Salim A, Alo K, Rhee P: Pedestrians injured by automobiles: Relationship of age to injury type and severity. Journal of the American College of Surgeons 2004; 199(3):382-387.

(18) Boström L, Nilsson B: Pedestrians who Required Admission to Hospital after Collisions with Motor Vehicles in Sweden from 1987 to 1994. European Journal of Surgery 2001; 167:810-815.

(19) Copeland A: Pedestrian Fatalities - The Metropolitan Dade County Experience, 1984-1988. The American Journal of Forensic Medicine and Pathology 1991; 12(1):40-44.

(20) Ryan G, McLean A, Vilenius A, Kloeden C, Simpson D, Blumbergs P, Scott G: Brain injury patterns in fatally injured pedestrians. Journal of Trauma 1994; 36(4):469-476.

(21) Richter D, Hahn M, Ostermann PAW, Ekkernkamp A, Muhr G: Vertical deceleration injuries: a comparative study of the injury patterns of 101 patients after accidental and intentional high falls. Injury 1996; 27(9):655-659.

(22) Türk E, Tsokos M: Pathologic Features of Fatal Falls From Height. The American Journal of Forensic Medicine and Pathology 2004; 25(3):194-199.

(23) Yagmur Y, Güloglu C, Aldemir M, Orak M: Falls from flat-roofed houses: a surgical experience of 1643 patients. Injury 2004; 35:425-428.

(24) Scalea T, Goldstein A, Phillips T, Sclafani S, Panetta T, McAuley J, Shaftan G: An Analysis of 161 Falls from a Height: The 'Jumper Syndrome'. The Journal of Trauma 1986; 26(8):706-712.

(25) Steedman D: Severity of free-fall injury. Injury 1989; 20:259-261.

(26) Velmahos G, Demetriades D, Theodorou D, Cornwell III E, Belzberg H, Asensio J, Murray J, Berne T: Patterns of Injury in Victims of Urban Free-Falls. World Journal Surgery 1997; 21:816-821.

(27) Høidrup S, Sørensen T, Grønbæk M, Schroll M: Incidence and characteristics of falls leading to hospital treatment: a one-year population surveillance study of the Danish population aged 45 years and over. Scandinavian Journal of Public Health 2003; 31:24-30.

(28) Cummins BH, Potter JM: Head Injury Due To Falls From Heights. Injury 1970; 2(1):61-64.

(29) Hein P, Schulz E: [Accident-fall induced craniocerebral injury]. Beitrag Gerichtliche Medizin 1989; 47:447-450.

(30) Preuß J, Padosch SA, Dettmeyer R, Driever F, Lignitz E, Madea B: Injuries in fatal cases of falls downstairs. Forensic Science International 2004; 141(2-3):121-126.

(31) O'Neill TW, Varlow J, Silman AJ, Reeve J, Reid DM, Todd C, Woolf AD: Age and sex influences on fall characteristics. Annals of Rheumatic Diseases 1994; 53(11):773-775.

(32) Hartshorne N, Harruff R, Alvord EJr: Fatal Head Injuries in Ground-Level Falls. The American Journal of Forensic Medicine and Pathology 1997; 18(3):258-264.

(33) Johnstone A, Zuberi S, Scobie W: Skull fractures in children: a population study. Journal of Accident & Emergency Medicine 1996; 13:386-389.

(34) Helling TS, Watkins MR, Evans LL, Shook JW, Van Way CW: Low Falls: An Underappreciated Mechanism of Injury. Journal of Trauma 1999; 46(3):453-456.

(35) Nelson E, Melton J3, Annegers J, Laws ER, Offord K: Incidence of skull fractures in Olmsted County, Minnesota. Neurosurgery 1984; 15(3):318-324.

(36) Shkrum M, Ramsay D: Craniocerebral and Vertebrospinal Trauma; in: Amy Thau, (ed): Forensic Pathology of Trauma - Common problems for the pathologist. Totowa, New Jersey, Humana Press Inc., 2007, pp 519-606.

(37) Yoganadan N, Pintar FA: Biomechanics of temporo-parietal skull fracture. Clinical Biomechanics (Bristol, Avon) 2004; 19:225-239.

(38) Morris A, Hassan A, Mackay M, Hill J: Head Injuries In Lateral Impact Collisions. Accident Analysis and Prevention 1995; 27(6):749-756.

(39) Yoganandan N, Pintar F, Sances A Jr, Walsh P R, Ewing C L, Thomas D J, Snyder R G: Biomechanics of Skull Fracture. Journal of Neurotrauma 1995; 12(4):659-668.

(40) Voo L, Kumaresan S, Pintar F, Yoganandan N, Sances AJr: Finite-element models of the human head - Review. Medical & Biological Engineering & Computing 1996; September:375-381.

(41) Delye H, Verschueren P, Depreitere B, Verpoest I, Berckmans D, Vander Sloten J, Van der Perre G, Goffin J: Biomechanics of Frontal Skull Fracture. Journal of Neurotrauma 2007; 24(10):1576-1586.

(42) Verschueren P, Delye H, Depreitere B, Van Lierde C, Haex B, Berckmans D, Verpoest I, Goffin J, Vander Sloten J, Van der Perre G: A new test set-up for skull fracture characterisation. Journal of Biomechanics 2007; 40(15):3389-3396.

(43) McElhaney JH: Mechanical properties of cranial bone. Journal of Biomechanics 1970; 3:495-511.

(44) Wood JL: Dynamic response of human cranial bone. Journal of Biomechanics 1971; 4:1-12.

(45) Gurdjian E: Deformation Studies Of The Skull: Mechanisms Of Skull Fracture; Impact Head Injury - Mechanistic, Clinical and Preventive Correlations. Springfield, Illinois, Charles C Thomas, 1975, pp 113-138.

(46) McElhaney JH, Hopper RH Jr., Nightingale RW, Myers B: Mechanisms of Basilar Skull Fracture. Journal of Neurotrauma 1995; 12(4):669-678.

(47) Rowbotham GF: The mechanisms of injuries of the head; Acute Injuries Of The Head. Edinburgh and London, E.& S.Livingstone Ltd, 1964, pp 56-69.

(48) Kremer C, Racette S, Dionne C-A, Sauvageau A: Discrimination of Falls and Blows in Blunt Head Trauma: Systematic Study of the Hat Brim Line Rule in Relation to Skull Fractures. Journal of Forensic Sciences 2008; 53(3):716-719.

(49) Yartsev A, Langlois NEI: A comparison of external and internal injuries within an autopsy series. Medicine, Science and Law 2008; 48(1):51-56.

(50) Harvey F, Jones A: "Typical" Basal Skull Fracture of Both Petrous Bones: An Unreliable Indicator of Head Impact Site. Journal of Forensic Sciences 1980; 25(2):280-286.

(51) Gordon I, Shapiro HA, Berson SD: Regional injuries of medico-legal importance; Head injuries; Forensic Medicine - A Guide To Principles. Edinburgh London Melbourne and New York, Churchill Livingstone, 1988, pp 252-269.

(52) Gan YC, Charkravarty D, Flint G: Ring fracture of the skull base: case report and review of the literature. British Journal of Neurosurgery 2002; 16(3):300-303.

(53) Voigt GE, Skold G: Ring fractures of the base of the skull. Journal of Trauma 1974; 14(6):494-505.

(54) Bauer KH. Der Bruch der Schädelbasis. Borchard A, Nordmann O, editors. Verhandlungen Der Deutschen Gesellschaft Für Chirurgie. Archiv Für Klinische Chirurgie 196, 460. 1939. Berlin, Julius Springer.

(55) Leestma J, Grcevic N: Impact Injuries to the Brain and Head; in: Kirkpatrick JB, (ed): Forensic Neuropathology. New York, Raven Press, 1988, pp 184-252.

(56) Gupta SM, Chandra JM, Dogra T: Blunt force lesions related to the heights of a fall. The American Journal of Forensic Medicine and Pathology 2004; 3(1):35-43.

(57) Hein PM, Schulz E: Contrecoup fractures of the anterior cranial fossae as a consequence of blunt force caused by a fall. Acta Neurochirurgica 1990; V105(1):24-29.

(58) Hirsch C, Kaufman B: Contrecoup skull fractures. Journal of Neurosurgery 1975; 42(May):530-534.

(59) Brink O, Vesterby A, Jensen Jr: Pattern of injuries due to interpersonal violence. Injury 1998; 29(9):705-709.

(60) Schuknecht B, Graetz K: Radiologic assessment of maxillofacial, mandibular, and skull base trauma. European Radiology 2005; 15(3):560-568.

(61) Connor SEJ, Flis C: The contribution of high-resolution multiplanar reformats of the skull base to the detection of skull-base fractures. Clinical Radiology 2005; 60(8):878-885.

(62) Jacobsen C, Lynnerup N: Cranial fractures caused by blunt trauma to the skull - A retrospective analysis of medicolegal autopsies in Denmark 1999-2004. Scandinavian Journal of Forensic Sciences 2008; accepted for publication.

Legends

Figure 1. Manner of death and age- and sex distribution

Table 1. Characteristics. The table shows the different trauma types, the distribution of individuals for each trauma type and the overall relation to the manner of death.

Table 2. The fracture types, their anatomical orientation and localisation. The table shows the fracture classification with the different fracture types and their anatomic localisation.

Table 3. The regional classification and the number of external injuries. The table shows the classification of injuries and the number of injuries related to cranial fractures.

Figure 2. Distribution between number of fracture related injuries and the total registered number of injuries in each classified region.

Table 4. The overall fracture types and their related impact regions. The table shows the relation between the different fracture types and the impact regions. The table is subdivided into linear fracture types and the different other fracture types as well as the regional impact classification.

Table 5. Linear fractures, their orientation, their related impact regions and trauma types. The table shows the relation between the linear fractures, impact region and trauma type. The table is subdivided by trauma type, fracture orientation and the different regional impact classifications and their associated regions.

Table 6. Other fracture types, their related impact regions and trauma types. The table shows the relation between the different other fracture types, impact regions and trauma types. The table is subdivided by trauma type, the different regional impact classifications and the associated regions.

Figure 1. Manner of death and age- and sex distribution

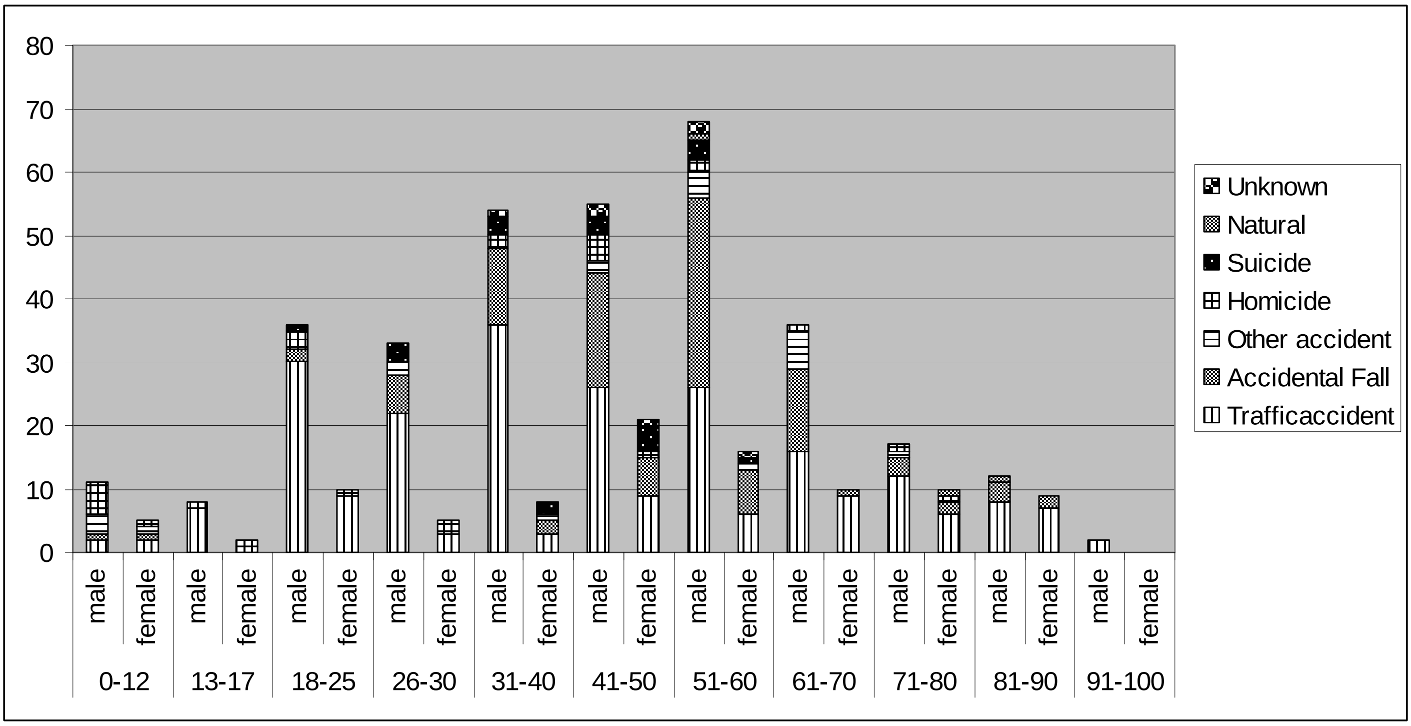

Table 1. Characteristics. The table shows the different trauma types, the distribution of individuals for each trauma type and the overall relation to the manner of death.

		Manner of death					Total
Trauma type		Accident	Homicide	Suicide	Natural	Unknown	n
Traffic	Car occupant Driver	75		4		1	80
	Car occupant Front seat passenger	13					13
	Car occupant Back seat passenger	10					10
	Pedestrian	53					53
	Bicycle riders	39					39
	Motorcycle riders	32					32
Other	Train	3		5			8
Other	Airplane	8					8
Other	Other traffic roles	9		1			10
	Subtotal						*253*
Falls/jumps from heights	Ground level	39	4		3	2	48
	2 - 3 metres	31				1	32
	3 - 5 metres	16					16
	> 5 metres	10		9			19
	No height known	13		1		1	15
	Subtotal						*130*
Hit/struck by blunt object and/or interpersonal violence	Hit/struck/compressed by blunt object	16	18				34
	Blows and kicks		4				4
	Subtotal						*38*
Other		5				2	7
Total		372	26	20	3	7	428

Table 2. **The fracture types, their anatomical orientation and localisation.** The table shows the fracture classification with the different fracture types and their anatomic localisation.

	Linear			Other fracture types							
	l	t	o/c	Depressed	Multiple	Spider web	Ring fracture	Comminute	Combination	Inconclusive	Total
Base and vault	27	53	31	15	17	1		54	31	5	234
Base	50	45	25	4	1	1	15	5	8	3	157
Vault	7	9	4	3	4	1		3	3	3	37
Total	84	107	60	22	22	3	15	62	42	11	428

l - longitudinal
t - transverse
o/c - oblique or combination

Table 3. **The regional classification and the number of external injuries.** The table shows the classification of injuries and the number of injuries related to cranial fractures.

External injuries associated to fractures	n
One region	181
Neighbouring regions	112
> 3 regions	10
Opposite regions	8
Whole scalp	32
No lesions	29
Non relatable	50
Other lesions	6
Total	428

Figure 2. Distribution between number of fracture related injuries and the total registered number of injuries in each classified region.

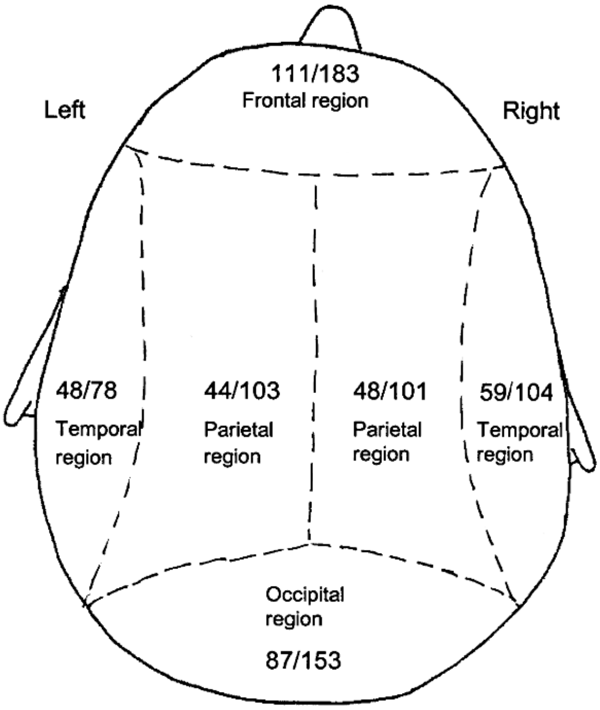

Table 4. **The overall fracture types and their related impact regions.** The table shows the relation between the different fracture types and the impact regions. The table is subdivided into linear fracture types and the different other fracture types as well as the regional impact classification.

	Linear fractures				Other fracture types									
	l	T	o/c	sub total	Depressed	Multiple	Spiderweb	Ring fracture	Comminute	Combination	sub total	Subtotal Linear + Others	Inconclusive	Total
I. One region														
Frontal	*8*	*5*	*9*	22		*6*			*9*	*5*	20	42		*42*
Occipital	*45*	*1*	*14*	60	*2*	*2*	*1*	*3*	*2*	*5*	15	75	*2*	*77*
Parietal	*4*	*12*	*1*	17	*5*				*2*	*3*	10	27		*27*
Temporal	*2*	*22*	*3*	27	*3*	*1*			*1*	*3*	8	35		*35*
Subtotal	59	40	27	126	10	9	1	3	14	16	53	179	2	181
II. Neighbouring regions														
Lateral	*2*	*18*	*6*	26	*3*	*3*	*1*		*5*	*3*	15	41	*1*	*42*
Lateral + Frontal	*3*	*13*	*6*	22	*4*	*3*		*1*	*9*	*6*	23	45	*2*	*47*
Lateral + Occipital		*3*	*5*	8	*1*				*2*	*4*	7	15		*15*
Other combinations		*2*	*2*	4		*1*			*2*		3	7	*1*	*8*
Subtotal	5	36	19	60	8	7	1	1	18	13	48	108	4	112
III. Other regional combinations	5	4	5	14	1	4			26	8	39	53	3	56
Subtotal (I+II+III)	69	80	51	200	19	20	2	4	58	37	140	340	9	349
No lesions	*4*	*9*	*4*	17		*1*	*1*	*6*	*2*	*1*	12	28	*1*	*29*
Non relatable	*11*	*18*	*5*	34	*3*	*1*		*5*	*2*	*4*	16	49	*1*	*50*
Total	84	107	60	251	22	22	3	15	62	42	168	417	11	428

l - longitudinal; t - transverse; o/c - oblique or combination

Table 5. **Linear fractures, their orientation, their related impact regions and trauma types.** The table shows the relation between the linear fractures, impact region and trauma type. The table is subdivided by trauma type, fracture orientation and the different regional impact classifications and their associated regions.

		Longitudinal												Transverse												Oblique or combination												Total
		One Region					Neighbouring R					Other		One Region					Neighbouring R					Other		One Region					Neighbouring R					Other		
	Trauma type	F	O	P	T	**n**	L	LF	LO	Ot	**n**		N	F	O	P	T	**n**	L	LF	LO	Ot	**n**		N	F	O	P	T	**n**	L	LF	LO	Ot	**n**		N	
Traffic	Car D	3	1			4						1	5	2		2	1	5	1	4			5	4	14	2				2	2				2	1	5	24
	Car F		2			2							2														1			1		1			1		2	4
	Car B																															1		1	2		2	2
	Cyclist		5			5	1				1		6		1	1	3	5	3	2			5		10		1	1	2	4	1	1			2	1	7	23
	Pedestrian		6			6						1	7	1		2	2	5	6	1		1	8		13						1		1		2	1	3	23
	Motorcyclist	1	2	1	1	5		1			1		6	1			2	3	2		1		3		6	3			1	4				1	1		5	17
	Other		1	1	1	3							3				2	2							2													5
	Subtotal	**4**	**17**	**2**	**2**	**25**	**1**	**1**			**2**		**27**	**4**	**1**	**5**	**10**	**20**	**12**	**7**	**1**	**1**	**21**	**4**	**41**	**5**	**2**	**1**	**3**	**11**	**4**	**3**	**1**	**2**	**10**	3	**24**	**98**
Falls	Groundlevel	2	15			17		2			2		19			1	5	6				1	1		7		4			4			2		2	1	7	33
	2-3 m		8			8	1				1		9			3	3	6		2	1		3		9		3			3		2			2	1	6	24
	3-5 m		2			2							2			1	2	3	1	1			2		5	2	1			3							3	10
	> 5 m	1	1			2							2				1	1	1				1		2	1				1							1	5
	No height known		2	1		3							3			1		1		1			1		2		1			1		1	2		3		4	9
	Subtotal	**3**	**28**	**1**		**32**	**1**	**2**			**3**		**35**			**6**	**11**	**17**	**2**	**4**	**1**	**1**	**8**		**25**	**3**	**9**			**12**		**3**	**4**		**7**	2	**21**	**81**
Accident	S/C	1				1							1	1			1	2	1	1			2		4		1			1							1	6
	Subtotal	1				1							1	1			1	2	1	1			2		4		1			1							1	6
Interpersonal violence	Hit blunt object											2	2						1	1	1		3		3						1				1		1	6
	B/K																		2				2		2						1				1		1	3
	Subtotal											2	**2**						**3**	**1**	**1**		**5**		**5**						**2**				**2**		**2**	**11**
Other				1		1						1	2			1		1							1	1	2			3							3	6
Total		**8**	**45**	**4**	**2**	**59**	**2**	**3**			**5**	5	**69**	**5**	**1**	**12**	**22**	**40**	**18**	**13**	**3**	2	**36**	**4**	**80**	**9**	**14**	**1**	**3**	**27**	**6**	**6**	**5**	**2**	**19**	5	**51**	**199**

Neighbouring R - neighbouring regions, Other - Other regional combinations
F - frontal, O - occipital, P - parietal, T - Temporal, L - lateral, LF - Lateral and Frontal, LO - Lateral and occipital, Ot - Other
Car D - Car driver, Car F - Car Front seat passenger, Car B - Car Back seat passenger, S/C - struck/compressed, B/K - blows/kicks

Table 6. **Other fracture types, their related impact regions and trauma types.** The table shows the relation between the different other fracture types, impact regions and trauma types. The table is subdivided by trauma type, the different regional impact classifications and the associated regions.

		depressed fracture											
		OR					NR					OC	
		F	O	P	T	n	L	LF	LO	Ot	n		N
Traffic	Car D			1		1							1
	Car F			1		1		2			2		3
	Car B												
	Cyclist											1	1
	Pedestrian						1				1		1
	Motor cyclist			1		1							1
	Other												
	Subtotal			**3**		**3**	**1**	**2**			**3**	**1**	**7**
Falls/jumps from heights	Ground level						1				1		1
	2-3 m							1			1		1
	3-5 m												
	> 5 m		1		1	2			1		1		3
	No height			1	1	2							2
	Subtotal		**1**	**1**	**2**	**4**	**1**	**1**	**1**		**3**		**7**
Accident	S/C				1	1	1				1		2
	Subtotal				**1**	**1**	**1**				**1**		**2**
Interpersonal violence	Hit blunt object		1			1		1			1		2
	B/K												
	Subtotal		**1**			**1**		**1**			**1**		**2**
Other				1		1							1
Total			**2**	**5**	**3**	**10**	**3**	**4**	**1**		**8**	**1**	**19**

		multiple fractures											
		OR					NR					OC	
		F	O	P	T	n	L	LF	LO	Ot	n		N
Traffic	Car D	2				2	1				1	3	6
	Car F												
	Car B	1				1		1			1		2
	Cyclist	1				1							1
	Pedestrian						1	1		1	3		3
	Motor cyclist	1				1							1
	Other	1				1		1			1		2
	Subtotal	**6**				**6**	**2**	**3**		**1**	**6**	**3**	**15**
Falls/jumps from heights	Ground level						1				1		1
	2-3 m											1	1
	3-5 m												
	> 5 m		1			1							1
	No height												
	Subtotal		**1**			**1**	**1**				**1**	1	**3**
Accident	S/C				1	1							1
	Subtotal				**1**	**1**							**1**
Interpersonal violence	Hit blunt object		1			1							1
	B/K												
	Subtotal		**1**			**1**							**1**
Other													
Total		**6**	**2**		**1**	**9**	**3**	**3**		**1**	**7**	4	**20**

		Ring fracture											
		OR					NR					OC	
		F	O	P	T	n	L	LF	LO	Ot	n		N
Traffic	Car D												
	Car F												
	Car B												
	Cyclist		1			1							1
	Pedestrian		1			1		1			1		2
	Motor cyclist												
	Other		1			1							1
	Subtotal		**3**			**3**		**1**			**1**		**4**
Falls/jumps from heights	Ground level												
	2-3 m												
	3-5 m												
	> 5 m												
	No height												
	Subtotal												
Accident	S/C												
	Subtotal												
Interpersonal violence	Hit blunt object												
	B/K												
	Subtotal												
Other													
Total			**3**			**3**		**1**			**1**		**4**

		Comminut fracture											
		OR					NR					OC	
		F	O	P	T	n	L	LF	LO	Ot	n		N
Traffic	Car D	3				3	1	2	1		4	9	16
	Car F			1		1		1			1	2	4
	Car B							2			2	1	3
	Cyclist	1				1			1	1	2		3
	Pedestrian		1		1	2	1	3		1	5	1	8
	Motor cyclist	3				3							3
	Other	2				2						9	11
	Subtotal	**9**	**1**	**1**	**1**	**12**	**2**	**8**	**2**	**2**	**14**	**22**	**48**
Falls/jumps from heights	Ground level												
	2-3 m												
	3-5 m											1	1
	> 5 m		1	1		2	1				1		3
	No height						1				1		1
	Subtotal		**1**	**1**		**2**	**2**				**2**	1	**5**
Accident	S/C											3	3
	Subtotal											**3**	**3**
Interpersonal violence	Hit blunt object						1	1			2		2
	B/K												
	Subtotal						**1**	**1**			**2**		**2**
Other													
Total		**9**	**2**	**2**	**1**	**14**	**5**	**9**	**2**	**2**	**18**	26	**58**

		Combination												Total
		OR					NR					OC		
		F	O	P	T	n	L	LF	LO	Ot	n		N	
Traffic	Car D	2		1		3		1			1	1	5	28
	Car F			1		1							1	8
	Car B													5
	Cyclist				2	2		1	1		2		4	10
	Pedestrian	1	1	1		3		1			1	3	7	21
	Motor cyclist							1			1	2	3	8
	Other								1		1	1	2	16
	Subtotal	**3**	**1**	**3**	**2**	**9**		**4**	**2**		**6**	**7**	**22**	**96**
Falls/jumps from heights	Ground level		1			1							1	3
	2-3 m						1		1		2		2	4
	3-5 m		1			1		2			2		3	4
	> 5 m		1			1							1	8
	No height		1			1							1	4
	Subtotal		**4**			**4**	**1**	**2**	**1**		**4**		**8**	**23**
Accident	S/C				1	1							1	7
	Subtotal				**1**	**1**							**1**	**7**
Interpersonal violence	Hit blunt object	1				1	2		1		3	1	5	10
	B/K	1				1							1	1
	Subtotal	**2**				**2**	**2**		**1**		**3**	1	**6**	**11**
Other														1
Total		**5**	**5**	**3**	**3**	**16**	**3**	**6**	**4**		**13**	8	**37**	**138**

OR - one region; NR - neighbouring regions, OC - Other regional combinations
F - frontal, O - occipital, P - parietal, T - Temporal, L - lateral, LF - Lateral and Frontal, LO - Lateral and occipital, Ot - Other
Car D - Car driver, Car F - Car Front seat passenger, Car B - Car Back seat passenger, S/C - struck/compressed, B/K - blows/kicks

Craniocerebral Trauma - Congruence between Post-mortem Computed Tomography Diagnoses and Autopsy Results

A 2-year retrospective study

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Abstract

Computed Tomography (CT) has been used routinely at the Department of Forensic Medicine, University of Copenhagen since 2002. A retrospective study was performed in order to correlate CT-scan based diagnoses of cranial and cerebral lesions with autopsy diagnoses in 56 cases. The CT-scans were performed by a forensic pathologist. They were obtained by using two different CT-scan protocols. The results showed correct skull fracture diagnoses in 34/56 cases. Fractures were diagnosed partially (9) or missed totally (13) on CT-images in 22 cases. The agreement for fracture diagnoses of the anterior, medial and posterior cranial fossae was 20%, 51,7% and 60%, respectively. Fractures involving bilateral bones were diagnosed correctly more frequently. The diagnostic agreement regarding brain injuries varied from 0%-79%. Both the autopsy-reports and CT-scan descriptions need to be standardized in order to secure more exact comparisons in the future.

Keywords: Forensic Pathology; Forensic Radiology; Computed Tomography; Craniocerebral Trauma; Skull Fractures; Brain Injuries

1. Introduction

Traumatic head injuries are common and have a high morbidity and mortality, which has been analyzed in a number of studies [1-8]. In the field of forensic pathology this is reflected by a large number of cases with fatal head injuries caused in accidents, suicides and homicides. The demonstration of the causative mechanism by analyzing the traumatic injuries is an important part of the forensic pathologic work and demands diagnostic accuracy and precision. Until a few years ago, the demonstration of traumatic head injuries was mostly done during autopsy supplemented by radiography and histology. New diagnostic possibilities in forensic pathology have been provided with the introduction of Computed Tomography Scanning (CT) and Magnetic Resonance Imaging (MR) in forensic medical practice. Internationally there have been a number of studies regarding the use of CT and MR in forensic pathology [9-21]. Previous studies have illustrated both advantages and limitations regarding this subject [9-21], but further research is needed to critically evaluate the role of CT and MR in forensic pathology. The aim of this retrospective study was to analyze the agreement concerning the anatomic localization and distribution of cranial fractures and brain injuries as they were diagnosed firstly by CT and by the following autopsy.

2. Materials and Methods:

Our study is based upon medico-legal autopsies performed at our institute in the years 2003 and 2004. In this period 1621 autopsies were performed, with 578 bodies being CT-scanned prior to autopsy in 2003 (70.1%), and 380 (47.6%) in 2004, respectively. The scan-operator was a physician with approximately 13 years of experience in forensic pathology. The CT-scans were routinely performed immediately after the medico-legal external examination and the scan-operator did not receive any information about the circumstances regarding the deaths. The CT-scan based diagnoses thus reflected the routine workflow conditions.

A total of 56 cases were included (2003: 39; 2004: 17) comprising 43 males and 13 females, with an age-range from newborn to 85 years (mean age: 39.2 years). The cases were selected by manually sorting the autopsy-reports for cases with an autopsy diagnosis of fracture of the neurocranium and a performed CT-scan prior to the autopsy. Cases with fractures of the viscerocranium only or the cervical column were not included. The 56 cases comprised homicides, suicides and accidents (manner of death), involving blunt and sharp trauma, gunshot, falls and traffic accidents (cause of death) (see Table 1). The material was generally characterized by severe head-injuries, and in the autopsy reports 20 of the 56 cases were diagnosed with a crushed cranium.

The CT-scans were obtained by a Spiral Siemens Somatom Plus 4. Two standard protocols for head scans were used during the period: 27 cases were scanned with 8 mm slices and pitch 1 (“protocol A”) and 28 cases were scanned with 3 mm slices and pitch 1.5 (“protocol B”). The protocols had been established with the consultancy of a radiographic technician. Only very few of the cases were scanned with both protocols. In one case there was no information about the used scan protocol. The use of two protocols was during the period dependent on the expected injuries and was thus a compromise between cost, effectiveness, resources and time-consumption in the daily routine work.

The autopsy reports and the CT-scan reports were compared regarding the diagnosis of cranial fractures. The diagnoses based upon the CT-scans were made by the scan operator. It was not possible to re-evaluate the CT-scans for this study. As a first approximation we assessed whether the diagnosed fractures comprised only the cranial vault, or the cranial base, or both, as diagnosed on CT-scan and at autopsy, and cross-tabulated the results dependent on the usage of scan-protocol. The data are presented raw in order to reflect the routine work conditions genuinely. We then subdivided the fractures according to whether they affected the anterior, medial and posterior fossae and cross-tabulated the results in the same fashion. Finally, the diagnostic frequencies of the fractured cranial bones were compared. We also registered whether brain injuries had been observed macroscopically at the autopsy and on the CT-scan. Histological analysis of cerebral injuries found macroscopically is not performed routinely at our institute and was also not performed in the included cases.

3. Results

3.1. Congruence of the CT-scan based fracture diagnoses with the autopsy diagnoses

A simple cross-tabulation between the fracture diagnoses made by CT-scan according to the used protocol and at autopsy, focusing only on whether the fracture involved the cranial vault and base, is seen in Table 2. The fracture diagnoses were equivalent in 34 cases, i.e. in 34/56 cases fractures diagnosed during autopsy had been diagnosed in the same location as on CT-scan. Fractures were not diagnosed at all on CT-scan in 13 cases, and the full extent of combined vault and base fractures was not realized on CT-scan in 9 cases. The fractures involving only the vault (n=3) were missed, while approximately half of the fractures involving only the cranial base (n=6) were missed.

Twenty of the 27 cases involving fracture of the cranial vault and base were cases with total crushing of the cranium, which was easily evident upon CT-scanning regardless of the scan protocol used (Figure 1). In thirteen cases fractures were missed on the CT-scan. The missed fractures localized in only the cranial vault (n=3) and both the cranial base and vault (n=4) were described as fissures in the autopsy-reports, which could explain why these fracture-systems were missed on the CT-scan. Scan protocol A had been used in 10 of the 13 cases were no fracture had been diagnosed at all.

Table 3 shows the congruence between autopsy and CT-scan according to the used scan protocol regarding fractures of the cranial fossae. Diagnosing fractures involving the anterior and posterior fossae by CT-scan was more difficult than identifying fractures involving the medial or posterior fossae, apparently regardless of whether protocol A or B was used. Regarding the medial fossa however, there was a marked difference. The use of protocol B seemed to greatly facilitate diagnosing the fractures.

Table 4 shows the cranial bones in which fractures were diagnosed on CT-scan versus by autopsy. Most cases often involved several bones. The temporal and sphenoid bones of the cranium were frequently involved both unilaterally and bilaterally, which is consistent with the high number of fractures in the anterior and medial fossae. Approximately half (54%) of the bilateral fractures of the temporal bones were diagnosed, while the unilateral fractures not were diagnosed frequently (12%). The same pattern was seen for the parietal bone, as bilateral fractures were more often diagnosed correctly on CT-scan than the unilateral fractures (42.8% and 26%, respectively). The fractures were diagnosed as unilateral on CT-scan in 6 cases of the bilateral temporal bone fractures and in one case of the bilateral parietal bone fracture. The unilateral and bilateral fractures of the sphenoid bones were diagnosed correctly in approximately half of the cases (40% and 50%), but only in less than a quarter when concerning the frontal bone (23, 5%). Furthermore, none of the three fractures of the ethmoid bone were diagnosed on CT-scan. Fractures in the occipital bone were diagnosed in 72% of the cases (Fig. 2 and 3). Nine of the 12 cases which on the CT images were diagnosed with bilateral temporal fractures were scanned with protocol B, as were 5 of the 6 cases diagnosed with bilateral sphenoid fractures. Apart from this no diagnostic difference between the uses of scan protocol A or B was noted.

3.2. Congruence of the CT-scan based brain injury diagnoses and autopsy diagnoses

There was generally equivalence regarding the diagnoses of brain injuries based upon CT-scan and autopsy (Table 5a-b). Often several types of injuries were seen in each case. The cases with subarachnoid and subdural hemorrhages were diagnosed relatively often (62.5% and 69.2%, respectively). This is also reflected in the measurement of inter-observer agreement which is substantial for both subarachnoid (κ=0.622) and subdural hemorrhage (κ=0.728) but poor for epidural hematoma (κ=0). We checked the description of the subarachnoid hemorrhages in the autopsy-reports of the cases where the hemorrhage had not been diagnosed on CT scan. There was no consistent pattern as the subarachnoid hemorrhages varied in severity and location. The dimensions of the subdural hemorrhages were, except from one case, not described in the autopsy-reports. The diagnostic frequency in this material did not differ whether scan-protocol A or B was used. Interestingly, there were a few cases of CT-scan based diagnoses of subarachnoid hemorrhage (n=2), subdural hematoma (n=1) and epidural hematoma (n=1), which were not diagnosed at the autopsy.

The diagnostic frequency of cerebral injuries (contusions, lacerations, edema and incarceration) varied somewhat. Contusions were diagnosed on CT scan but not at autopsy in 13 cases and this inconsistency is reflected by the inter-observer agreement which is slight (κ=0.181). Lacerations were diagnosed relatively often on CT-scan (79.2%, κ=0.727 substantial agreement), while only half of the cases with edema were diagnosed and the inter-observer agreement was moderate (κ=0.515). None of the cases with incarceration were diagnosed on CT-scan (κ=0). Overall, the diagnostic frequency of these lesions did not seem to differ dependent on the scan protocol.

4. Discussion

Diagnostic CT-scanning of bodies prior to forensic autopsies has become increasingly used in forensic pathology. Several studies have analyzed the advantages of CT imaging for forensic purposes, performed both peri-mortem [9, 10] and post-mortem [11-16], with differing results. Several studies have analyzed different forensic issues in a problem-based manner to exemplify the advantages and possibilities of forensic radiology [12, 13, 17-20]. However, the actual settings in which CT and MR imaging is to be incorporated in the daily routine of the forensic institutes remain to be established. Undoubtedly, the implementation of these modalities is a question of both scarcity of research regarding their application in forensic pathology, as well as an appraisal of the resources, costs and effectiveness entailed by these techniques [21]. Postmortem CT imaging has been a routine at the institute in Copenhagen since 2002 [21], and in our experience the balance between CT-scanning for routine or research needs to be addressed. One obvious way of assessing the implementation of CT-scanning in forensic pathological practice is to analyze if diagnostic capabilities are improved.

Our results are based on material from a period when CT-scanning at our institute had just been established. Two head CT-scan protocols, A and B, were used routinely. Limitations of this study were its retrospective nature and the exclusive use of only one of the scan-protocols in a problem based manner in the daily routine work which made a comparison between the two protocols difficult. Therefore apart from inter-observer agreement (κ-coefficients) no statistical analyses were performed and the results therefore only reflect tendencies.

The results show that CT scan based diagnosis of fracture of the neurocranium is straightforward in large fracture-systems. These fracture-systems, with splintering of several bones, are often altered during the autopsy and reconstruction can be difficult. The CT images and 3-dimensional reconstructions may provide an excellent, preliminary overview of the fracture-system for the forensic pathologist prior to the autopsy, and may illustrate the fracture-system for non-medical professions, e.g. in court presentations or case reconstructions [12, 13, 15, 16, 22]. However, our results show that the diagnosis of fractures in the anterior and medial cranial fossae based on CT-scan was difficult. Especially in cases with fissures the diagnostic frequency was low. This is also exemplified by the low CT-scan based diagnostic frequency of fractured bones related to the anterior fossae (ethmoid, frontal and temporals) and medial fossae (temporals and sphenoids). Approximately half of the cases were scanned with the high resolution protocol B, which seemed to facilitate diagnoses of fractures in the medial fossae but apparently had no effect on the diagnostic frequency of fractures in the anterior fossae. This is also the case in clinical settings where the detection of fractures in these anatomic regions is a difficult task and requires thorough examination [23, 24]. For paired bones it was evident that the diagnostic frequency was higher as soon as the fractures involved both bones. The bilateral involvement of paired bones is most probably due to the cranium being subjected to a greater force resulting in more extensive fractures with dislocation or gaping which is easily diagnosed on CT-scan. Using a scan protocol with a higher resolution seemed to heighten the diagnostic agreement regarding bilateral fractures located in the medial fossae, although it did not seem to differ regarding unilateral fractures. In a forensic pathology setting the diagnosis of the whole fracture-system is important since it may provide clues of possible impact-points and thereby a possible causation [25]. In this regard the diagnoses of fractures in the anterior or medial fossae is essential since they may provide information about the causative mechanism, e.g. a fall or a blow to the head [26], especially when cerebral lesions are missing.

Our results concerning the CT-scan based diagnoses of intracranial lesions were congruent with other studies, which noted that lesions smaller than the used slice thickness were missed on CT images due to limited resolution [12, 16]. We found a substantial agreement between CT and autopsy regarding subarachnoid hemorrhage, subdural hemorrhage and cerebral lacerations. The agreement between CT and autopsy regarding contusions was only slight and it is noteworthy that we found a higher frequency of contusions based on CT-scanning than at autopsy. It is possible that the small contusions were overlooked at the autopsy. Histological analyses and further studies are needed to examine this discrepancy further. The same holds true for the diagnoses of cerebral edema, which often is a macroscopic, observer-dependent diagnosis at the autopsy, which is difficult to diagnose [27] These results might suggest that the autopsy is not necessarily the golden standard regarding certain lesions, as it has been suggested by Yen et al. [12]. In the clinical setting CT is the method of choice for the imaging of acute head-trauma, since it demonstrates lesions of the scalp, bone, brain membranes and cerebral lesions well [28, 29]. MR is also increasingly being used in the forensic pathology setting [12]. It is considered to be superior to CT for detecting suspected parenchymal pathologic changes or for the monitoring of parenchymal lesions especially in the posttraumatic phase [28, 29]. Yen et al. found that cerebral contusions and hemorrhages were visualized equally or slightly better on CT than MR [12]. Since much of the forensic postmortem imaging is performed on traumatic and often instant deaths, CT would seem to be the method of choice. In cases where death occurs some time after the trauma or where a possible dating of traumatic lesions is important, MR imaging may be more useful. It has for example been reported that hemosiderin deposition can be visualized on MR images for many months after a hemorrhage [30].

Overall our results also reflect the circumstances of how routine post-mortem CT-scanning was implemented at our institute. If CT-scanning had been performed without the limitations imposed by the routine work procedures the diagnostic frequency might possibly have been higher. CT-scanning was performed in order to supplement the autopsy and demonstrate the possible cranial and cerebral injuries prior to the autopsy. However, it may be argued that a more satisfactory use of CT would be to select the most appropriate scan protocol depending on which lesions might be expected. This means that the scan-operator must have knowledge of the circumstances of death prior to CT-scanning. For example, in a case where possible differentiation between a blow to the head and a fall is needed, the routine protocol should be altered in order to enhance the visualization of the cranial base. Adjusting protocols in a problem-based manner demands a technically well-founded scan-operator which today is not necessarily implicit in a post-mortem scan setting. Therefore, when performing post-mortem CT-scanning in general, a decision has to be made whether the scans are supposed to generate material for research, routine-work or both and which specific posed forensic problem CT or MR scans have to solve or aid solving.

The CT scan images in this study were not diagnosed by a radiologist but by a forensic pathologist who during the time period in question CT-scanned approximately 950 bodies. When CT-scanning was introduced at our institute, the assumption was that post-mortem CT scanning produced images which might be foreign for the clinical radiologist, especially concerning the expected lesions and their interpretation in a forensic context. For example, it had been experienced that morphological changes caused by cadaverosis, livores and gas-formation had made the interpretation of postmortem CT-scans by a radiologist with no pathological experience difficult (K. Poulsen, personal communication). In both peri- and post-mortem studies which made use of a clinical radiologist the need of forensic training is stressed [12]. Forensic radiology is a field between radiology and forensic pathology and regardless of which specialty forms the basis the need for either radiologic or forensic training is obvious and necessary. Given this, and to ensure that CT (and MR) is implemented in a competent and advantageous fashion in a forensic setting, it becomes paramount that the CT-scanning reports and autopsy reports are standardized [12]. This ensures diagnostic uniformity, and allows for a more straightforward evaluation of diagnostic agreement and observer variation (both at autopsy and at CT-scanning). The autopsy reports are to date the golden standard in most settings, but we found that, e.g., cerebral contusions were often diagnosed at CT-scanning but where not mentioned in the autopsy-reports. This general problem has also been noted in other studies [12, 16] and a possible solution for a standardized database has been suggested [31].

The evolving technology has for some years now improved CT-scanning procedures by decreasing scan-time and making faster image acquisition possible. While certainly not at this point being a substitute for a full autopsy, CT-scanning is an important addition to the forensic pathological "tool-box". We find that the diagnostic precision still needs to be improved. On the other hand, the capability for 3-D visualisation for complex cranial fracture systems and the ability to possibly diagnose cerebral lesions which are not evident at autopsy are real advantages. Finally, the digital nature of CT- or MR-images may make use of autopsy data in new ways, e.g., biomechanical analyses. This will open future possibilities for investigating, and reconstructing, injury patterns.

5. Conclusion

The present study shows the existing forensic-radiologic diagnostic challenges for craniocerebral injuries caused by head trauma and also exemplifies the importance of using the correct technical CT-scan setting depending on the pathology. Thereby the advantages and limitations of the craniocerebral CT-scan in an environment with routine post-mortem CT-scan are illustrated. Due to the variable diagnostic frequency CT scans performed in a post-mortem setting and also CT scans which have not been performed for forensic purposes can not be expected to be precise enough for diagnosing every aspect of head trauma. Having this in mind CT-scan in our setting can not substitute the autopsy, but the CT scans serve as an invaluable supplement to the autopsy. Standardization of the autopsy and CT-scan reports along with forensic or radiologic training of the personnel performing and diagnosing CT-scans is needed in order to heighten the diagnostic accuracy and frequency. Systematic research at least across the forensic and radiologic specialty is needed in order to establish the role of radiologic examination modalities in forensic pathology.

Acknowledgements

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Reference List

[1] Ingebrigtsen Tor, Mortensen Kim, Bertil Romner, The Epidemiology of Hospital-Referred Head Injury in Northern Norway, Neuroepidemiology 17 (1998) 139-146.

[2] A.Engberg, T.Teasdale, Epidemiologi og behandling af hovedtraumer i Danmark 1994-2002, belyst ved sygehusstatistik, Ugeskrift for læger 169 (2007) 199-203.

[3] B.Jennett, Epidemiology of head injury, Archives of the Diseases of Childhood 78 (1998) 403-406.

[4] J.y.Jiang, H.Feng, Z.Fu, G.Guo-yi, L.Wei-ping, L.Wei-guo, L.Lian-shen, L.Xiao-jie, Q.Suo-kai, X.Wei, Y.Xiao-feng, Y.Rui-tong, Z.Sai, Violent head trauma in China: report of 2254 cases, Surgical Neurology 68 (2007) S2-S5.

[5] S.Kleiven, P.M.Peloso, H.v.Holst, The epidemiology of head injuries in Sweden from 1987 to 2000, Injury Control & Safety Promotion 10 (2003) 173.

[6] W.I.Steudel, F.Cortbus, K.Schwerdtfeger, Epidemiology and prevention of fatal head injuries in Germany - trends and the impact of the reunification, Acta Neurochirurgica 147 (2005) 231-242.

[7] F.Tagliaferri, C.Compagnone, M.Korsic, F.Servadei, J.Kraus, A systematic review of brain injury epidemiology in Europe, Acta Neurochirurgica 148 (2006) 255-268.

[8] L.Tiret, E.Hausherr, M.Thicoipe, B.Garros, P.Maurette, J.P.Castel, F.Hatton, The Epidemiology of Head Trauma in Aquitaine (France), 1986: A Community-Based Study of Hospital Admissions and Deaths, International Journal of Epidemiology 19 (1990) 133-140.

[9] M.Bauer, S.Polzin, D.Patzelt, The use of clinical CCT images in the forensic examination of closed head injuries, Journal of Clinical Forensic Medicine 11 (2004) 65-70.

[10] K.Molina, J.Nichols, DiMaio VJM, The Sensitivity of Computed Tomography (CT) Scans in Detecting Trauma: Are CT Scans Reliable enough for Courtroom Testimony?, The Journal of Trauma 63 (2007) 625-629.

[11] B.Hoey, J.Cipolla, M.Grossmann, N.McQuay, P.Shukla, S.Stawicki, C.Stehly, W.Hoff, Postmortem Computed Tomography, "CATopsy", Predicts Cause of Death in Trauma Patients, The Journal of Trauma 63 (2007) 979-986.

[12] K.Yen, K.O.Lövblad, E.Scheurer, C.Ozdoba, M.J.Thali, E.Aghayev, C.Jackowski, J.Anon, N.Frickey, K.Zwygart, J.Weis, R.Dirnhofer, Post-mortem forensic neuroimaging: Correlation of MSCT and MRI findings with autopsy results, Forensic Science International 173 (2007) 21-35.

[13] M.Thali, K.Yen, W.Schweitzer, P.Vock, R.Dirnhofer, Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem MSCT and MRI, Journal of Forensic Science 48 (2003) 386-403.

[14] S.Paperno, T.Riepert, B.Krug, M.A.Rothschild, A.Schultes, M.Staak, L.Lackner, Prospektive Untersuchung zur Wertigkeit der postmortalen Computertomographie im Vergleich zur Autopsie, RöFo - Fortschritte auf dem Gebiet der Röntgenstrahlen und der Bildgebenden Verfahren (2005) 130-136.

[15] P.Leth, S.Christoffersen, Computertomografi anvendt ved retsmedicinske obduktioner, Ugeskrift for læger 170 (8 A.D.) 444-447.

[16] K.Poulsen, J.Simonsen, Computed tomography as routine in connection with medico-legal autopsies, Forensic Science International 171 (2007) 190-197.

[17] S.Bolliger, M.Thali, S.Ross, U.Buck, S.Naether, P.Vock, Virtual autopsy using imaging: bridging radiologic and forensic sciences. A review of the Virtopsy and similar projects, European Radiology 18 (2008) 273-282.

[18] M.J.Thali, M.Braun, J.Wirth, P.Vock, R.Dirnhofer, 3D surface and body documentation in forensic medicine: 3-D/CAD Photogrammetry merged with 3D radiological scanning, Journal of Forensic Sciences 48 (2003) 1356-1365.

[19] I.Roberts, E.Benbow, R.Bisset, J.Jenkins, S.Lee, H.Reid, A.Jackson, Accuracy of magnetic resonance imaging in determining cause of sudden death in adults: comparison with conventional autopsy, Histopathology 42 (2003) 424-430.

[20] H.Ezawa, R.Yoneyama, S.Kandatsu, K.Yoshikawa, H.Tsujii, K.Harigaya, Introduction of autopsy imaging redefines the concept of autopsy: 37 cases of clinical experience, Pathology International 53 (2003) 865-873.

[21] G.N.Rutty, Are Invasive Autopsies Necessary?, Forensic Science, Medicine and Pathology 1-2 (2005) 71-73.

[22] C.Jacobsen, C.A.Schön, B.Kneubuehl, M.J.Thali, E.Aghayev, Unusually extensive head trauma in a hydraulic elevator accident: Post-mortem MSCT findings, autopsy results and scene reconstruction, Journal of Forensic and Legal Medicine 15 (2008) 462-466.

[23] B.Schuknecht, K.Graetz, Radiologic assessment of maxillofacial, mandibular, and skull base trauma, European Radiology 15 (2005) 560-568.

[24] S.E.J.Connor, C.Flis, The contribution of high-resolution multiplanar reformats of the skull base to the detection of skull-base fractures, Clinical Radiology 60 (2005) 878-885.

[25] E.Gurdijan, Deformation Studies of the Skull: Mechanisms of Skull Fracture, Impact Head Injury - Mechanistic, Clinical and Preventive Correlations, Charles C Thomas, 19 A.D., pp. 113-125.

[26] C.Hirsch, B.Kaufman, Contrecoup skull fractures, Journal of Neurosurgery 42 (1975) 530-534.

[27] R.Hausmann, C.Vogel, S.Seidl, P.Betz, Value of morphological parameters for grading of brain swelling, International Journal of Legal Medicine 120 (2006) 219-225.

[28] J.Provenzale, CT and MR imaging of acute cranial trauma, Emergency Radiology 14 (2007) 1-12.

[29] N.Besenski, Traumatic injuries: imaging of head injuries, European Radiology 12 (2002) 1237-1252.

[30] J.Wardlaw, P.Statham, How often is hemosiderin not visible on routine MRI following traumatic intracerebral haemorrhage, Neuroradiology 42 (2000) 81-84.

[31] E.Aghayev, L.Staub, R.Dirnhofer, T.Ambrose, C.Jackowski, K.Yen, S.Bolliger, A.Christe, C.Roeder, M.Aebi, M.J.Thali, Virtopsy - The concept of a centralized database in forensic medicine for analysis and comparison of radiological and autopsy data, Journal of Forensic and Legal Medicine 15 (2008) 135-140.

Legends

Table 1. Manner and cause of death

Table 2. Cross-tabulation between a correct diagnosis regarding fractures involving the anatomic entities cranial base and/or vault sorted into groups according to the used scan protocol. The data are presented raw.

Table 3. Congruence between autopsy and CT-scan according to used scan protocol regarding fracture of the cranial base. The total is higher than 56 cases due to involvement of several fossae in one case.

Table 4. Case-based congruence between CT-scan diagnosis and autopsy diagnosis of fractures.

Table 5a. Distribution regarding the diagnoses of extra-axial hemorrhage by autopsy and CT scan.

Table 5b. Distribution of diagnoses regarding cerebral lesions by autopsy and CT scan.

Figure 1. 3-dimensional reconstruction of a skull diagnosed as crushed at the autopsy and on the CT-scan.

Figure 2. Axial CT image of the cranial base of a man who fell down a well of stairs. The point of impact with a contusion wound was in the occiput. The figure shows the fracture in the occipital bone as it was seen on CT images.

Figure 3. Image of the same cranial base as in figure 2 as it was seen at the autopsy.

Table 1. Manner and cause of death

Manner of death Cause of death	Homicide	Suicide	Accidents	Total
Blunt trauma *-Traffic-accident* *-Fall* *-other*	3	4	38 *27* *10* *1*	45 *27* *10* *1*
Sharp trauma	1	0	0	1
Gunshot	6	4	0	10
Total	10	8	38	56

Table 2. Cross-tabulation between a correct diagnosis regarding fractures involving the anatomic entities cranial base and/or vault sorted into groups according to the used scan protocol. The data are presented raw.

Autopsy CT-scan (A/B protocol)	Vault and base	Vault	Base	Total
Vault and base	27 (11/15)*	0	0	27 (11/15)
Vault	2 (2/0)	0	0	2 (2/0)
Base	7 (3/4)	0	7 (1/6)	14 (4/10)
No fracture	4 (4/0)	3 (2/1)	6 (4/2)	13 (10/3)
Total	40 (20/19)	3 (2/1)	13 (5/8)	56 (27/28)

* In one case there was no information about whether scan-protocol A or B was used

Table 3. Congruence between autopsy and CT-scan according to used scan protocol regarding fracture of the cranial base. The total is higher than 56 cases due to involvement of several fossae in one case.

Anatomic Localization	Autopsy	CT-scanning Usage of protocol A/B	Congruence CT-scanning (Protocol A/B)		No congruence CT-scanning (Protocol A/B)
Fossa anterior	20	10/10	4 (3/1)	20%	16 (7/9)
Fossa medialis	29	15/14	15 (4/11)	51,7%	14 (11/3)
Fossa posterior	15	9/6	9 (5/4)	60%	6 (4/2)
Total	64	34/30	28 (12/16)	43,8%	36 (22/14)

Table 4. Case-based congruence between CT-scan diagnosis and autopsy diagnosis of fractures

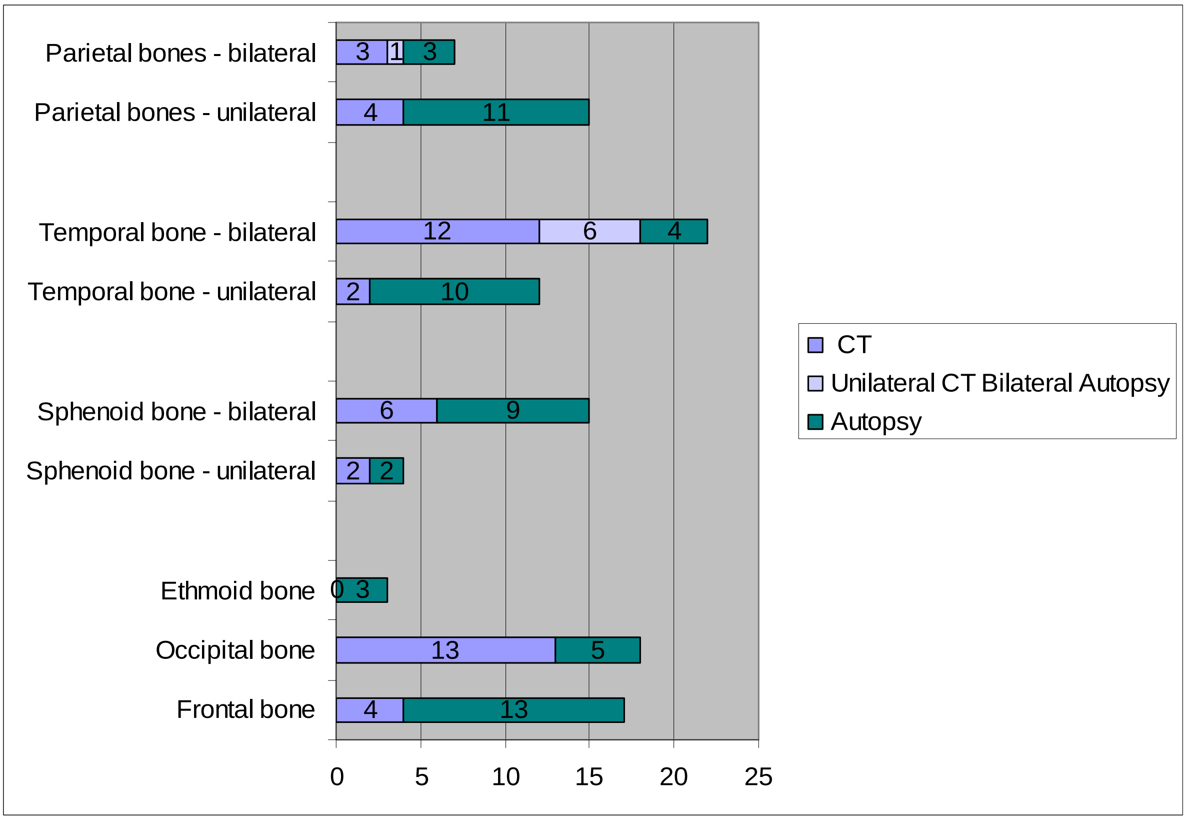


Table 5a. Distribution regarding the diagnoses of extra-axial hemorrhage by autopsy and CT scan.
The κ-coefficients are presented for each diagnosis: Subarachnoid hemorrhage κ=0.622; Subdural hematoma κ=0.728; Epidural hematoma κ=0

Autopsy / CT scan		Subarachnoid hemorrhage		Subdural hematoma		Epidural hematoma	
		+	-	+	-	+	-
Subarachnoid hemorrhage	+	10	2				
	-	6	38				
Subdural hematoma	+			9	1		
	-			4	42		
Epidural Hematoma	+					0	1
	-					0	55

Table 5b. Distribution of diagnoses regarding cerebral lesions by autopsy and CT scan

The κ-coefficients are presented for each diagnosis: Brain contusion κ= 0.181; Brain laceration κ=0.727; Brain edema κ=0.515; Incarceration κ=0

Autopsy / CT scan		Brain contusion		Brain laceration		Brain edema		Incarceration	
		+	-	+	-	+	-	+	-
Brain Contusion	+	23	13						
	-	9	11						
Brain laceration	+			19	2				
	-			5	26				
Brain edema	+					5	3		
	-					4	44		
Incarceration	+							0	0
	-							5	51

Figure 1. 3-dimensional reconstruction of a skull diagnosed as crushed at the autopsy and on the CT-scan

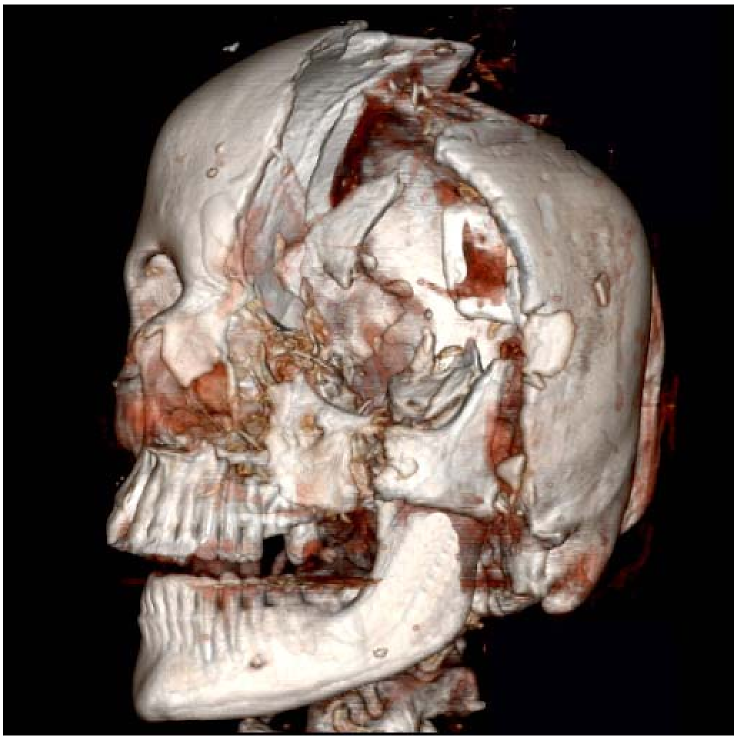
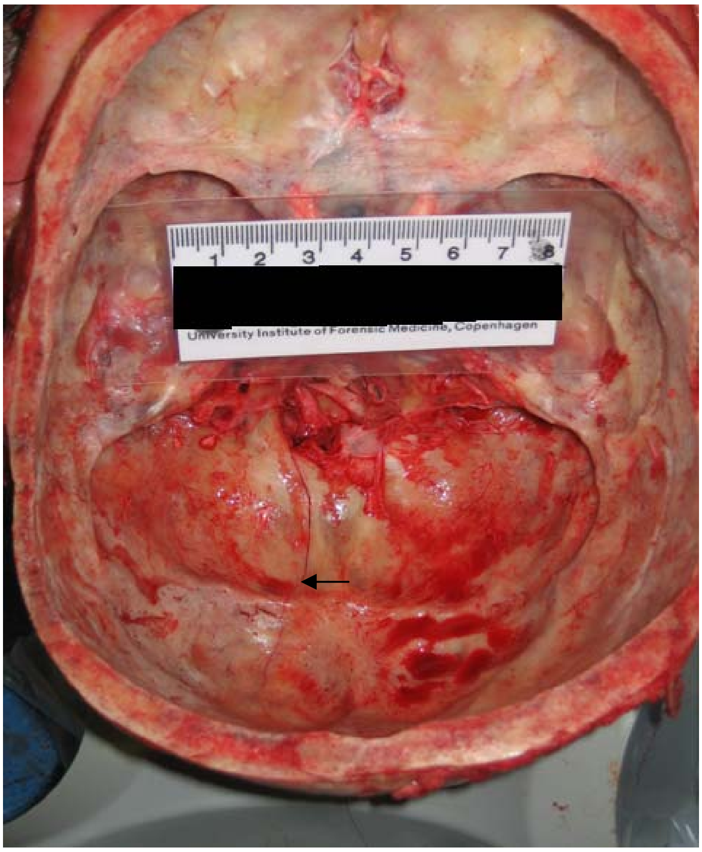


Figure 2. Axial CT image of the cranial base of a man who fell down a stair case. The point of impact with a contusion wound was in the occiput. The figure shows the fracture in the occipital bone as it was seen on CT images.

Figure 3. Image of the same cranial base as in figure 2 as it was seen at the autopsy.



A comparative study of cranial, blunt trauma fractures as seen at medicolegal autopsy and by Computed Tomography

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Abstract

Background

Computed Tomography (CT) has become a widely used supplement to medicolegal autopsies at forensic institutes throughout the world. Amongst other things, it has proven to be very valuable in visualising fractures of the cranium. CT scan data have in the past years been used to create head models for biomechanical trauma analysis by Finite Element Analysis. If CT scan data in the future is to be used for creating individual head models for retrograde trauma analysis we need to ascertain how well cranial fractures are captured by CT scan. The purpose of this study was to compare the diagnostic agreement between CT and autopsy regarding cranial fractures and especially the precision with which cranial fractures are recorded.

Methods

The autopsy fracture diagnosis was compared to the diagnosis of two CT readings (by a forensic pathologist and a radiologist and based on Multiplanar and Maximum Intensity Projection reconstructions) by registering the fractures on schematic drawings. Also, the extent of the fractures was quantified by merging 3-dimensional datasets from both the autopsy as input by 3D digitizer tracing and CT scan.

Results

The results showed a good diagnostic agreement regarding fractures localised in the posterior fossa, while the fracture diagnosis in the medial and anterior fossa was difficult at the first CT scan reading. The fracture diagnosis improved during the second CT scan reading. Thus using two different CT reconstructions improved diagnosis in the medial fossa and at the impact points in the cranial vault. However, fracture diagnosis in the anterior fossa and of hairline fractures in general still remained difficult.

Conclusions

The study showed that the forensically important fracture systems to a large extent were diagnosed on CT images using Multiplanar and Maximum Intensity Projection reconstructions. Difficulties remained in the minute diagnosis of hairline fractures, located especially in the anterior and medial fossa. These inconsistencies need to be resolved in order to use CT scan data of victims for individual head modelling and trauma analysis. New generation CT scanners will probably improve the diagnostic frequency.

Background

Computed tomography (CT) scanning of bodies prior to medicolegal autopsy has become a powerful tool in several forensic institutes throughout the world [1-3]. Indeed, there may be a number of advantages to performing a CT scan before a medicolegal autopsy. The scans of the head are suitable to visualize lesions of especially bone, but also soft tissue and cerebral pathologic changes or lesions [4]. Fractures, intracranial hemorrhages and hematomas can be demonstrated both 2- and 3-dimensionally, providing a general overview of simple as well as complex lesions, e.g., gun-shot lesions or large fracture systems [3,5-8]. The scans are non-invasive and have been claimed to be observer-independent and objective [2].

Due to the nature of the technique, CT scanning also allows for the collection of spatial data of the cranium, which potentially could be used in the development of new analytical tools in forensic pathology and injury biomechanics [9,10]. Biomechanical models of the head are increasingly used in the forensic sciences to analyze injury mechanisms [11-13]. CT scan data may be particularly useful for creating biomechanical models [14-16] of bodyparts, e.g. the cranium [17-20], because they may provide spatial, digital data which represent the complex anatomic structures of the cranium of the single individual. The possibility of being able to develop either standard or individual cranial models subject to retrograde trauma analysis with Finite Element Analysis could open up for new prospects regarding medicolegal case work both in adults and children.

We have shown that it may be difficult to visualize non-dislocated fractures of the cranium on CT scans performed in a routine setting[21], especially when the fractures are located in the cranial base. Forensically important information about the whole fracture system and possible impact points may then be lost in the cases in which these fractures provide clues about the causative forces. If CT scan data of victims with minor fracture systems are to be used in future retrograde biomechanical modelling, we need to not just examine the overall diagnostic agreement between CT scanning and autopsy, but also to examine in more detail exactly how fractures seen on CT scans match autopsy finds.

To this end we performed a detailed analysis of 14 cases with cranial fractures by carefully recording the fractures as diagnosed on CT scans post processed with Multiplanar reconstruction (MPR) [22] and Maximum Intensity Projection (MIP) [23], as well as by detailed recording of the fractures at autopsy (drawing and photos). We further tried to quantify the differences by tracing the fractures as seen at autopsy using a 3-dimensional digitizer and merging this 3-dimensional data set with a 3-dimensional reconstruction of fractures diagnosed on CT scan.

Methods

The study included fourteen cases (13 male, 1 female; age-range: 19-82 years, mean 47 years) with neurocranial fractures with a limited extension, caused by blunt violence. Nearly all of the cases were accidents (7 falls, 5 traffic-accidents) while one was the result of an assault with a baseball bat. In one case the manner of death was unknown.

Each body was scanned using a MSCT-scanner (Siemens Somatom Plus 4 Volume Zoom) prior to the autopsy. The scan was obtained in an axial plane using a slice collimation of 4 x 1 mm, pitch 0.65, 120 KV, mAs ~150 and bone algorithm (H60s).

At the autopsy, the cranium and the fractures were photographed and registered on a schematic drawing. Also, the fracture characteristics, extension and anatomic location were registered. For comparative purposes the neurocranium was divided into the following major anatomic regions: the vault (squamous part of the frontal bone, the parietal bones, the squamous part of the temporal bone) and the cranial base. The cranial base was further subdivided into the posterior fossa (occipital bone), the medial fossa (petrous part of the temporal bone, greater wing of the sphenoid, sella turcica) and the anterior fossa (orbital part of the frontal bone and the lesser wings of the sphenoid).

Two CT readings were performed. The first diagnostic fracture reading was performed by a forensic pathologist (CJ) on the Siemens scanner workstation. The axial images and a Multiplanar reconstruction (MPR) of the sagittal and coronal image planes with reconstruction increment of 0.5 mm were used. The second diagnostic reading of the same CT images was performed in cooperation with a board certified radiologist (BLH) on a Agfa Impax DS 3000 workstation. In addition to the MPR, a thick (5 mm) MIP was performed, and in selected cases a curved MPR. Due to technical difficulties one case did not undergo a second evaluation. Discontinuity or dislocation of the bone was defined as being a fracture. In some cases there was suture diastasis and to avoid interpreting these as fractures the width of the suture was compared to the parallel sutures. Intracranial air or blood in the sinuses served as an indicator for possible fractures, but if a discontinuity of the bone was not visible the likely associated fracture was not registered.

In order to compare the extension and anatomic localisation of the fractures, the fracture diagnosis of the first and second CT scan evaluation were registered on the schematic drawings from the autopsy. It was also noted whether the fractures were uni- or bilateral and, on the CT scans, whether there was fluid in the sinuses or mastoids. This clearly showed whether congruence between the autopsy and the reconstructed CT images (MPR, MIP and curved MPR) existed. The data were analyzed regarding the recognition of an overall fracture system, providing important information about the traumatology in forensic casework, and whether the overall as well as the minute fracture diagnosis was correct compared to the autopsy results.

In order to further quantify location and congruence between autopsy and CT scan we selected five cases, and their 3-dimensional fracture registrations based on the first reading of the CT scan data and on the autopsy were merged. We did this by performing a 3-dimensional fracture registration at the autopsy by tracing the fractures using a digitiser (Patriot® Polhemus, US). The CT scan data were transferred to Mimics®, a softwareprogramme which allows single slice editing and segmentation, enabling us to segment the fractures as seen on the CT images. The two obtained data sets, from the autopsy and the CT scan, were transferred to DesignCAD 3D Max 15®, a computer aided design package, and merged (see figure 1a, b and c).

At the autopsy the majority of the cases (12/14) comprised linear cranial fractures. There was also a case with a depressed fracture in the vault and one case with a local comminute fracture in the occiput. In half the cases several separate fractures were present per case, e.g., a linear fracture involving the posterior fossa and a separate fracture involving the medial fossa. Also more than half (n=9) of the fractures comprised a varying number of ramifications (n=1-5), which at the autopsy were seen as undislocated hairline fractures. Only a few of all the fractures were dislocated (n=4) and the fracture width varied from 4 mm - below 1 mm. Suture diastasis was involved in 5 cases and involved the lambdoid, squamous and sphenofrontal suture.

Results

It was seen at the autopsy that the basal fossae and the vault were affected in 34 instances (see table 1 and figure 2). The anterior and medial fossae were affected bilaterally in half the cases, while bilateral fractures in the posterior fossa only occurred once. Fractures involving the anterior fossa bilaterally (cases #6, #7, #13) never crossed the midline. The unilateral fractures in the anterior fossa (cases #1, #2, #11) were, except from one (case #11), continuations of fractures from the medial fossae (cases #1, #2) and were located in the sphenoid. Fractures involving the medial fossae (cases #1-7, #10-13) were separate fractures in two cases (cases #10, #13) but were mostly continuations of fractures from the posterior fossa (cases #5, #6, #11) or the vault (cases #1-4, #7). Four of the bilateral fractures in the medial fossae traversed the sella turcica (cases #3-5, #12).

The anatomic localisation and extent of the fractures was diagnosed completely during the first reading of the MPR CT images in two of the fourteen cases (cases #8, #14) (see figure 2). Case #8 comprised a simple linear fracture in the occipital bone oriented anterior-posterior. The fracture in case #14 was depressed, oriented anterior-posterior and located in the vault. In ten cases (#1-6, #9-12) there was a partial fracture diagnosis based on the MPR CT images, but the overall fracture system was recognized.
Table 2 shows the quantification of the fractures extent as measured by digitiser at the autopsy compared to the measurements performed on the CT scans after the first reading. The table shows that up to 50% of the full extent of the fractures was missed in one case (case #1). The missed fractures were hairline fractures. In cases #9, #6 and #11 the T- and H-shaped hairline fractures of the impact point was missed. In cases #11, #6 and #1 the hairline fractures located in the medial fossa, both in the petrous bone and the sphenoid, were not diagnosed. Case #14 represented the only depressed fracture in the material and in that case the diagnosis was correct.

By performing the second reading of the MPR and MIP CT images of 13 of the 14 cases (case #13 was excluded) the fractures of the cases #1, #3, #10 and #12 were diagnosed completely. In one case (case #7) important information, regarding contre-coup fractures, was missed on the CT-scan since fractures of the eyeloft in the anterior fossae were not diagnosed.

The missed fractures on the MPR CT images were characterised by being undislocated hairline fractures or ramifications of the wider fractures. Not surprisingly most of the missed fractures were located in the basal medial and anterior fossae (see table 3). Using thick MIP reconstructed CT images at the second evaluation did not facilitate the diagnosis of fractures in the minor wings of the sphenoid nor in the pars orbitalis of the frontal bone. The greatest advantage of using thick MIP reconstructed CT images was achieved in the medial fossa and in the vault when visualising ramifications related to impact points (see figure 3). In the medial fossa, using thick MIP improved the diagnostic frequency of fractures in the petrous part of the temporal bone (see figure 4) and the greater wings of the sphenoid by approximately 50%. The main fractures in the basal posterior fossa and the vault, except from five ramifications (cases #5, #6, #9-11), were diagnosed in the first evaluation. The ramifications were associated to impact points and were therefore important for the forensic casework. During the second evaluation, the usage of curved MPR on the CT images made the diagnosis of two of the ramifications possible (case #5 and #11) while the remaining ramifications were diagnosed by using thick MIP (case #6, #9 and #10).

In several cases there were indications of fracture on the CT images with fluid in the mastoid cells (case #1, #4, #10, #12, #13) which at the autopsy always was associated with fracture in the same petrous bone. In four of these cases there was also fluid in the sphenoid sinus on the CT images (case #4, #12, #13) and/or the ethmoid sinus (case #1, #4, #12). In two cases fracture of the sinus walls was diagnosed on the CT image. In only one of these cases an associated fracture in the anterior fossa was not diagnosed at the autopsy (case #4).

Discussion

During the last years CT scanning of the head for forensic purposes has become widely used to visualize lesions or pathological changes prior to autopsy [3,5,7]. Attempts have been made to use the acquired data for detecting causal relationships, either by illustrating and interpreting lesions based on CT images [6,8] and other tools [24], or by using the data to attempt biomechanical analysis [25] to analyze lesions.

The CT scan based recognition of fractures located in the basal cranial fossae and also the cranial vault is important both in the clinical setting regarding treatment efficiency [26-28] and in medicolegal material in order to be able to analyze injury mechanisms. However, in clinical settings the diagnosis of hairline fractures is mostly not essential as long as there are no clinical symptoms or complications [29]. The medicolegal material in this study reflected the trauma severity with a fracture involvement of the medial fossa in 80% of the cases, which in this study was an area in which fracture diagnosis was difficult. Often both the pars petrosa of the temporal bone and the sphenoid bone were affected simultaneously either unilaterally or bilaterally and there were also a few cases with transphenoidal fractures resulting in involvement of both fossa, which in clinical studies is interpreted as the result of severe head injury [30-34]. Unger et al [27] found in a clinical study that fractures of the cranial base predominantly were located in the sphenoid bone and to some extent in the temporal bone. In this study most fractures were identified in the greater wings of the sphenoid involving the orbital surface while fractures of the cerebral and temporal surfaces were less common. This finding might be related to the difficulties exemplified in this study in visualising these fractures on CT images. In our study none of the isolated fractures of the minor wing were diagnosed, which is in concordance with the study of Unger et al [27] in which only a few fractures of the minor wings of the sphenoid were diagnosed.

With the combination of MIP, MPR and in some instances curved MPR, the identification of fractures at possible impact points was deemed acceptable. It is known that widths of linear fractures at impact sites can be narrower than at locations further away from impact in the same case [17]. The recognition of a possible characteristic fracture corresponding to the impact point in the cranium and the correlation to possible scalp lesions and instruments is important for the casework, both from a biomechanical [17] and a forensic viewpoint.

The results implied difficulties regarding diagnosis of fractures involving the anterior fossa. In all our cases the fractures were confined to either side of the eyeloft without midline crossing and were forensically interpreted as being the result of an impact to the back of the head, i.e. contre-coup fractures of the eyeloft [35-38]. In most clinical studies fractures of the eyeloft are associated with trauma to the facial or frontal region [39-42] producing transverse and longitudinal fractures [43,44] and we are not aware of clinical studies which mention these characteristic fractures after occipital impact. In a forensic routine setting both fracture of the anterior fossa and lesions of the cerebral temporal and frontal lobes in conjunction with occipital impact would be regarded as contre-coup lesions and thereby indicative of this specific injury mechanism. Further studies are needed to elucidate how often cerebral lesions and/or fractures of the eyeloft occur in impacts to the back of the head.

The difficulties regarding diagnosis of fractures involving the anterior and medial fossa is also known in the clinical setting [26]. Schuknecht et al [22] stress the use of correct protocols when attempting to diagnose fractures of the bones in the medial and anterior fossa (thin collimation (0.75 - 1 mm) and 2D MPR with contiguous 2 mm slices in the axial and coronal plane) and especially high resolution (0.5 - 0.75 mm) for evaluation of the pars petrosa of the temporal bone. Philipp et al [45] found that thin MPR obtained from thin collimation (2 x 0.5 mm) was superior in subtle fracture detection compared to collimation of 4 x 1 mm in midline facial fractures.

Other 3-dimensional reconstructions aside from MIP [23] were not used in this study since the diagnostic improvement by using these reconstructions for visualizing non-dislocated and hairline fractures was not considered to be substantial compared to the 2-dimensional MPR images conf. [39,46,47]. However recent studies have shown a diagnostic improvement for particularly pathological changes in the temporal bone by using Volume Rendering reconstructions [48]. The use of high-resolution MPR's based on 0.625 mm collimations in a problem-based manner has also been found to improve the diagnostic frequency [49].

In this study we also wanted to try to more precisely measure the differences in determining fracture extent based on either CT scanning (MPR) and by direct inspection at autopsy. We were able to do this in five cases, and to our knowledge this represents the first such attempt at direct quantification. Fracture length discrepancies were thus measureable for hairline fractures. We feel that such precise quantification is necessary if CT data is to be used in future forensic, biomechanical injury modelling and Finite Element Analysis of minor fracture systems. One perspective of these techniques is the ability to perform retrograde injury modelling based on the specific case at hand, thereby complementing the general model based approach (see Raul et al. for an overview)[11]. While finite element models in forensics and accident analysis already have been applied to injury simulation [13,50,51], the retrograde analyses will depend much on the correct capture of the full fracture extent and impact area. Capturing less than half of the full fracture extent will necessarily result in a lower calculated impact force, and not capturing the fracture pattern correctly may also result in a wrong interpretation of the causative injury. Clearly there is a need to extend the quantification to a larger sample and other cranial fracture patterns. Further studies of standard models and simulations are also necessary to accumulate data on head injury biomechanics and validate the head models [50].

An indication for a fracture being present involving the basal cranial fossae can be the identification of intra cranial air [52,53], fluid in the sinuses [54] or opacification of the mastoid cells [49]. This was also the case in our material and these pathological changes led to fracture diagnosis in most of these cases. Connor et al [49] found that the specific use of high-resolution MPR's upon diagnosis of basal cranial fractures or indications hereof (opacified mastoid cells, etc.) on 5 mm axial images led to a higher diagnostic frequency. In our material there was also one case with fluid level in the sphenoid and ethmoid sinuses in conjunction with an occipital impact. There was no associated fracture of the anterior fossa. Fractures of the sinus walls are difficult to diagnose during an autopsy and in these cases CT images are of great advantage. Our material was too small to explore whether fractures of the sinus walls could be associated with impacts in the occiput and how often they occur without associated fracture of the anterior or medial fossa diagnosed during the autopsy. Geserick et al. [37] found in a prospective study that the orbital medial wall, roof and basal wall contained contre-coup fractures relating to occipital impacts. Also, other authors have found fractures of the orbital roof in similar cases [35,36]. It remains to be established how often fluid in the mastoids or the sinus is associated to fractures and whether this finding in the sinus alone is as relevant as contre-coup fractures in the eyeloft for possibly differentiating between a blow to the head or impact to the moving head (e.g. fall) [35].

Collaboration with a radiologist (BHB) increased the diagnostic frequency of the cranial fractures. During the second reading the difference between a clinical and forensic approach towards diagnosis of cranial fractures was clearly demonstrated. This emphasized the fact that forensic radiology should be an interdisciplinary specialty which will be dependent on input and knowledge from both specialties to evolve further [1,55].

Conclusion

Our study showed that the forensically important fracture systems to a large extent were diagnosed on CT images using MPR and MIP. Using various reconstructions and collaborating with a radiologist was beneficial and necessary in this type of cases with non-dislocated fractures and hairline fractures. Difficulties remained in the minute diagnosis of hairline fractures located especially in the anterior or medial fossa. This was exemplified by merging the digitised autopsy data with the data from the CT scan. The merges were performed based on fracture diagnosis after the first reading and it must be assumed that the amount of missed fractures would have decreased after the second reading. By using MIP, and in selected cases curved MPR, especially focusing on the fossae and at the impact points in the vault or occipital bone, lead to an increase in the diagnostic frequency, which in turn lead to an improvement of the diagnostic possibilities regarding forensically important information, e.g., possible causative events, agents and force directions. However the inconsistencies regarding the diagnosis of especially fractured eyelofts (contre-coup) was problematic and in the cases in which a differentiation between a fall on the back of the head or a blow is necessary the autopsy still seems to be the primary choice. Although we found that using different reconstructions improved the fracture visualisation, the agreement between the autopsy results and the CT image still needs to be improved, if CT scans of minor fracture systems are to be used for future retrograde biomechanical modelling and Finite Element Analysis. For the biomechanical evaluation of head injuries it is important to be able to recognize the extent and course of cranial fractures, including non-dislocated fractures and hairline fractures in order to be able to give an approximation of the injury mechanism and involved forces. If retrograde trauma analysis and individual head modelling in the future is to be based on CT-scan data a consistent and reliable fracture diagnosis is essential and the fractures must be captured fully by CT scan. In this technical study we focused only on minor fracture systems which limited the number of included cases and restricted the usage of statistical methods, including the evaluation of diagnostic sensitivity/specificity. Future larger blinded diagnostic studies could evaluate the congruence between autopsy and CT scan images further. Finally new generation CT scanners with the technical ability to produce isotropic volume data may probably improve the diagnostic frequency [56,57].

Abbreviations

CT - Computed Tomography; MPR - Multiplanar Reconstruction; MIP - Maximum Intensity Projection; MSCT - Multislice Computed Tomography

Competing interests

The authors state no competing interests.

Authors' contributions

CJ: conception and design of the study, data acquisition, image and data analysis, draft of manuscript. BHB: image and data analysis. NL: conception and design of the study, image and data analysis, draft of manuscript. All authors read and approved the final manuscript.

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Reference List

1. O'Donnell C, Rotman A, Collet S, Woodford N: **Current status of routine post-mortem CT in Melbourne, Australia.** *Forensic Science, Medicine and Pathology* 2007, **3:** 226-232.

2. Thali M, Yen K, Schweitzer W, Vock P, Dirnhofer R: **Virtopsy, a new imaging horizon in forensic pathology: virtual autopsy by postmortem MSCT and MRI.** *Journal of Forensic Science* 2003, **48:** 386-403.

3. Poulsen K, Simonsen J: **Computed tomography as routine in connection with medico-legal autopsies.** *Forensic Science International* 2007, **171:** 190-197.

4. Besenski N: **Traumatic injuries: imaging of head injuries.** *European Radiology* 2002, **12:** 1237-1252.

5. Leth P, Christoffersen S: **Computertomografi anvendt ved retsmedicinske obduktioner.** *Ugeskrift for læger* 8 A.D., **170:** 444-447.

6. Bauer M, Polzin S, Patzelt D: **The use of clinical CCT images in the forensic examination of closed head injuries.** *Journal of Clinical Forensic Medicine* 2004, **11:** 65-70.

7. Thali M, Jackowski C, Oesterhelweg L, Ross S, Dirnhofer R: **VIRTOPSY - The Swiss virtual autopsy approach.** *Legal Medicine* 2007, **9:** 100-104.

8. Oehmichen M, Gehl HB, Meissner C, Petersen D, Höche W, Gerling I *et al*.: **Forensic pathological aspects of postmortem imaging of gunshot injury to the head: documentation and biometric data.** *Acta Neuropathologica* 2003, **105:** 570-580.

9. Hayes W, Erickson M, Power E: **Forensic Injury Biomechanics.** *Annual Review Biomedicine England* 2007, **9:** 55-86.

10. Voo L, Kumaresan S, Pintar F, Yoganandan N, Sances AJr: **Finite-element models of the human head - Review.** *Medical & Biological Engineering & Computing* 1996, **September:** 375-381.

11. Raul JS, Deck C, Willinger R, Ludes B: **Finite-element models of the human head and their applications in forensic practice.** *International Journal of Legal Medicine* 2008, **122:** 359-366.

12. O'Riordain K, Thomas PM, Phillips JP, Gilchrist M: **Reconstruction of real world head injury accidents resulting from falls using multibody dynamics.** *Clinical Biomechanics* 2003, **18:** 590-600.

13. Raul J, Baumgartner D, Willinger R, Ludes B: **Finite element modelling of human head injuries by a fall.** *International Journal of Legal Medicine* 2006, **120:** 212-218.

14. Viceconti M, Zannoni C, Testi D, Cappello A: **A new method for the automatic mesh generation of bone segments from CT data.** *Journal of Medical Engineering & Technology* 1999, **23:** 77-81.

15. Young P, Beresford-West T, Coward S, Notarberardino B, Walker B, Abdul-Aziz A: **An efficient approach to converting three-dimensional image data into highly accurate computational models.** *Philosophical Transactions of The Royal Society* 2008, **366:** 3155-3173.

16. Gelaude F, Vander Sloten J, Lauwers B: **Accuracy assessment of CT-based outer surface femur meshes.** *Computer Aided Surgery* 2008, **13:** 188-199.

17. Yoganandan N, Pintar F, Sances A Jr, Walsh P R, Ewing C L, Thomas D J *et al.*: **Biomechanics of Skull Fracture.** *Journal of Neurotrauma* 1995, **12:** 659-668.

18. Bandak FA, Vander Vorst MJ, Stuhmiller LM, Mlakar PF, Chilton WE, Stuhmiller JH: **An Imaging-based Computational and Experimental Study of Skull Fracture: Finite Element Model Development.** *Journal of Neurotrauma* 1995, **12:** 679-688.

19. Bangash M, Al-Obaid Y, Bangash F, Bangash T: In *Trauma - An Engineering Analysis with Medical Case Studies Investigation*. Berlin Heidelberg New York: Springer; 2007:343-365.

20. Guan Y, Zhang J, Yoganandan N, Pintar F, Muszynski C, Gennarelli T: **Automating 3D meshing method for patient-specific modelling.** *Biomedical Sciences Instrumentation* 2006, **42:** 199-204.

21. Jacobsen C, Lynnerup N: **Craniocerebral Trauma - Congruence between Post-mortem Computed Tomography Diagnoses and Autopsy Results - A 2 year retrospective study.** *submitted* 2008.

22. Schuknecht B, Graetz K: **Radiologic assessment of maxillofacial, mandibular, and skull base trauma.** *European Radiology* 2005, **15:** 560-568.

23. Medina L: **Three-Dimensional CT Maximum Intensity Projections of the Calvaria: A New Approach for Diagnosis of Craniosynostosis and Fractures.** *American Journal of Neuroradiology* 2000, **21:** 1951-1954.

24. Bolliger S, Thali M, Ross S, Buck U, Naether S, Vock P: **Virtual autopsy using imaging: bridging radiologic and forensic sciences. A review of the Virtopsy and similar projects.** *European Radiology* 2008, **18:** 273-282.

25. Myers JC, Okoye MI, Kiple D, Kimmerle EH, Reinhard KJ: **Three-dimensional (3-D) imaging in post-mortem examinations: elucidation and identification of cranial and facial fractures in victims of homicide utilizing 3-D computerized imaging reconstruction techniques.** *International Journal of Legal Medicine* 1999, **113:** 33-37.

26. Provenzale J: **CT and MR imaging of acute cranial trauma.** *Emergency Radiology* 2007, **14:** 1-12.

27. Unger JM, Gentry LR, Grossman JE: **Sphenoid fractures: prevalence, sites, and significance.** *Radiology* 1990, **175:** 175-180.

28. Herbella FAM, Mudo M, Delmonti C, Braga FM, Del Grande JC: **"Raccoon Eyes" (periorbital haematoma) as a sign of skull base fracture.** *Injury* 2001, **32:** 745-747.

29. Goh K, Ahuja A, Walkden S, Poon W: **Is routine computed tomographic (CT) scanning necessary in suspected basal skull fractures?** *Injury* 1997, **28:** 353-357.

30. Harvey F, Jones A: **"Typical" Basal Skull Fracture of Both Petrous Bones: An Unreliable Indicator of Head Impact Site.** *Journal of Forensic Sciences* 1980, **25:** 280-286.

31. Kienstra M, Loveren HV: **Anterior Skull Base Fractures.** *Facial Plastic Surgery* 2005, **21:** 180-186.

32. Menon A, Pai VK, Rajeev A: **Pattern of fatal head injuries due to vehicular accidents in Mangalore.** *Journal of Forensic and Legal Medicine* 2008, **15:** 75-77.

33. Joslyn JN, Mirvis SE, Markowitz B: **Complex fractures of the clivus: diagnosis with CT and clinical outcome in 11 patients.** *Radiology* 1988, **166:** 817-821.

34. West OC, Mirvis SE, Shanmuganathan K: **Transsphenoid basilar skull fracture: CT patterns.** *Radiology* 1993, **188:** 329-338.

35. Hirsch C, Kaufman B: **Contrecoup skull fractures.** *Journal of Neurosurgery* 1975, **42:** 530-534.

36. Hein PM, Schulz E: **Contrecoup fractures of the anterior cranial fossae as a consequence of blunt force caused by a fall.** *Acta Neurochirurgica* 1990, **V105:** 24-29.

37. Geserick G, Prokop O, Kruse C: **[Frakturen der knöchernen Orbita bei stumpfem Schädeltrauma mit Contrecoup-Verletzungen].** *Kriminal- und Forensische Wissenschaften* 1980, **39:** 53-57.

38. Lignitz E, Henn V: **New autopsy signs in violent death.** *Forensic Science International* 2007, **165:** 172-177.

39. Buitrago-Tellez CH, Schilli W, Bohnert M, Alt K, Kimmig M: **A comprehensive classification of craniofacial fractures: postmortem and clinical studies with two- and three-dimensional computed tomography.** *Injury* 2002, **33:** 651-668.

40. Asano T, Ohno K, Takada Y, Suzuki R, Hirakawa K, Monma S: **Fractures of the Floor of the Anterior Cranial Fossa.** *The Journal of Trauma, Injury, Infection and Critical Care* 1995, **39:** 702-706.

41. Exadaktylos A, Sclabas G, Smolka K, Rahal A, Andres R, Zimmermann H *et al*.: **The Value of Computed Tomographic Scanning in the Diagnosis and Management of Orbital Fractures Associated with Head Trauma: A Prospective, Consecutive Study at a Level I Trauma Center.** *The Journal of Trauma, Injury, Infection and Critical Care* 2005, **58:** 336-341.

42. Hooper K: **Injuries of the skull.** In *Patterns of Acute Head Injury*. 1969:21-30.

43. Gurdjian ES, Webster JE, Lissner HR: **The Mechanism of Skull Fracture.** *Radiology* 1950, **54:** 313-339.

44. Vance B: **Fractures of the Skull - Complications and Causes of Death: A Review of 512 Necropsies and of 61 Cases studied Clinically.** *Archives of Surgery* 1927, **14:** 1023-1092.

45. Philipp M, Funovics M, Mann F, Herneth A, Fuchsjaeger M, Grabenwoeger F *et al*.: **Four-Channel Multidetector CT in Facial Fractures: Do we need 2 x 0.5 mm collimation?** *American Journal of Radiology* 2003, **180:** 1707-1713.

46. Brüning R, Quade R, Keppler V, Reiser M: **3-D-CT reconstructions in fractures of the skull base and facial skeleton.** RöFo - *Fortschritte auf dem Gebiet der Röntgenstrahlen und der Bildgebenden Verfahren* 1994, **160:** 113-117.

47. Ali Q, Dietrich B, Becker H: **Patterns of skull base fracture: a three-dimensional computed tomographic study.** *Neuroradiology* 1994, **36:** 622-624.

48. Fatterpekar G, Doshi A, Dugar M, Delman B, Naidich T, Som P: **Role of 3D CT in the Evaluation of the Temporal Bone.** *RadioGraphics* 2006, **26:** S117-S132.

49. Connor SEJ, Flis C: **The contribution of high-resolution multiplanar reformats of the skull base to the detection of skull-base fractures.** *Clinical Radiology* 2005, **60:** 878-885.

50. Marjoux D, Baumgartner D, Deck C, Willinger R: **Head injury prediction capability of the HIC, HIP, SIMon and ULP criteria.** *Accident Anlalysis and Prevention* 2008, **40:** 1135-1148.

51. Roth S, Raul J, Willinger R: **Biofidelic child head FE model to simulate real world trauma.** *Computer Methods and Programs in Biomedicine* 2008, **90:** 262-274.

52. Cihangiroglu M, Ozdemir H, Kalender O, Ozveren F, Kabaalioglu A: **Transverse sinus air after cranial trauma.** *European Journal of Radiology* 2003, **48:** 171-174.

53. Betz BW, Wiener MD: **Air in the temporomandibular joint fossa: CT sign of temporal bone fracture.** *Radiology* 1991, **180:** 463-466.

54. Laasonen E, Servo A, Sumuvori H: **Sphenoid Sinus Fluid Level in Skull-Base Fractures.** *European Journal of Radiology* 1982, **2:** 5-7.

55. Yen K, Lovblad KO, Scheurer E, Ozdoba C, Thali MJ, Aghayev E *et al*.: **Post-mortem forensic neuroimaging: Correlation of MSCT and MRI findings with autopsy results.** *Forensic Science International* **In Press, Corrected Proof**.

56. Parizel P, Van Goethem J, Özsarlak Ö, Maes M, Phillips C: **New developments in the neuroradiological diagnosis of craniocerebral trauma.** *European Journal of Radiology* 2005, **15:** 569-581.

57. Lane J, Lindell E, Witte R, DeLone D, Driscoll C: **Middle and Inner Ear: Improved Depiction with Multiplanar Reconstruction of Volumetric CT Data.** *RadioGraphics* 2006, **26:** 115-125.

Legends

Figure 1a, b and c.

3-dimensional data set from case #6 with the digitised fracture at the autopsy (a), the segmented fracture from the CT image (b) and the merged two data sets.

Figure 2.

Registration of the case based fracture congruity between autopsy and CT.

Figure 3.

MPR (right) and MIP (left) coronal images of fractures in the left temporal bone and right great wing of the sphenoid.

Figure 4.

MPR (right) and MIP (left) sagittal images of fractures in the occipital bone and petrous part of the temporal bone.

Table 1.

Case based number of fractures in the anatomic entities of the neurocranium

Table 2. Comparison of the digitised fracture length to the fracture length as measured on CT images of the first reading

Table 3. Number of fractures in each bone as diagnosed by autopsy versus CT-scan

Figures

Figure 1a, b and c.

3-dimensional data set from case #6 with the digitised fracture at the autopsy (a), the segmented fracture from the CT image (b) and the merged two data sets.

The dimensions are in mm and represent only some of the measurements. The 2-dimensional representation of the 3-dimensional image causes distortion.

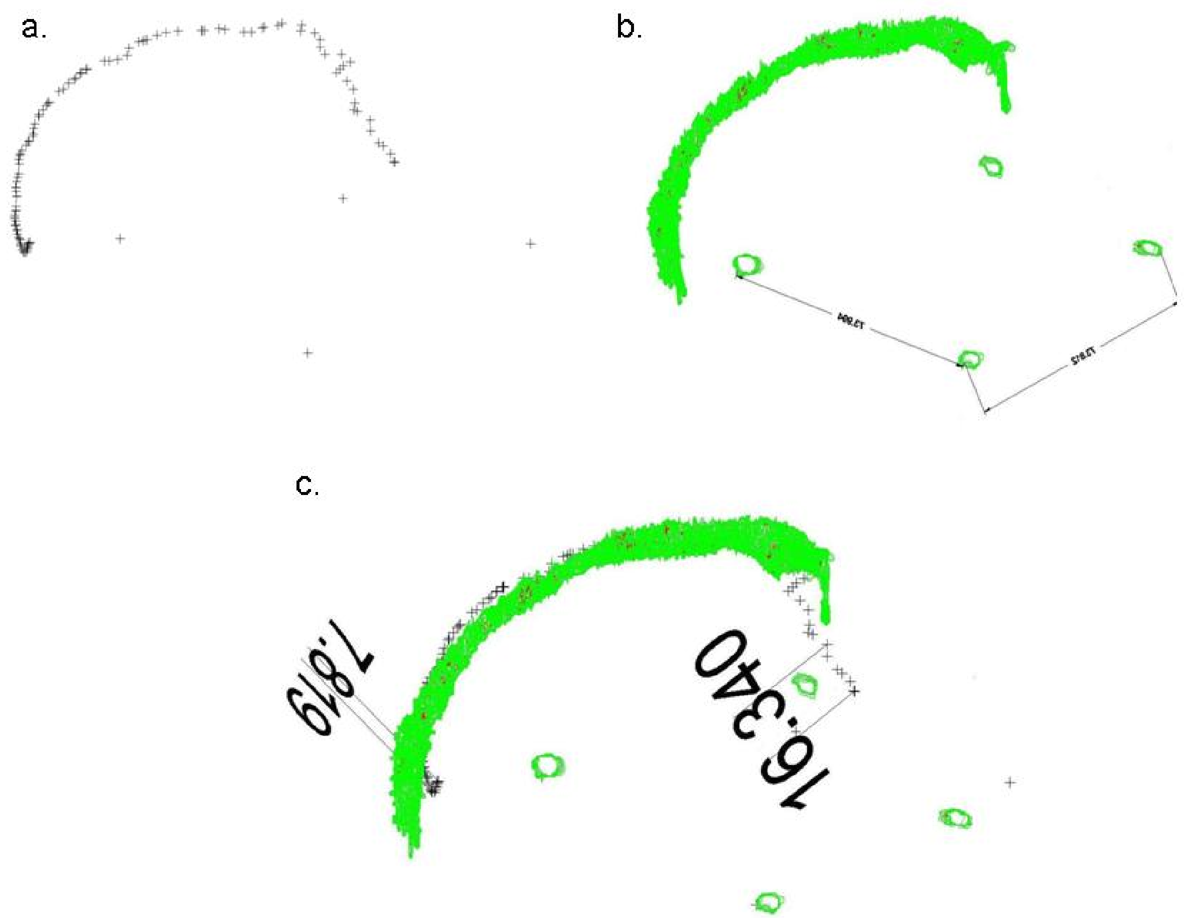


Figure 2.

Registration of the case based fracture congruity between autopsy and CT. The red colour represents the autopsy results while the blue colours represent the result of the first CT reading (light blue) and the second CT reading (dark blue).

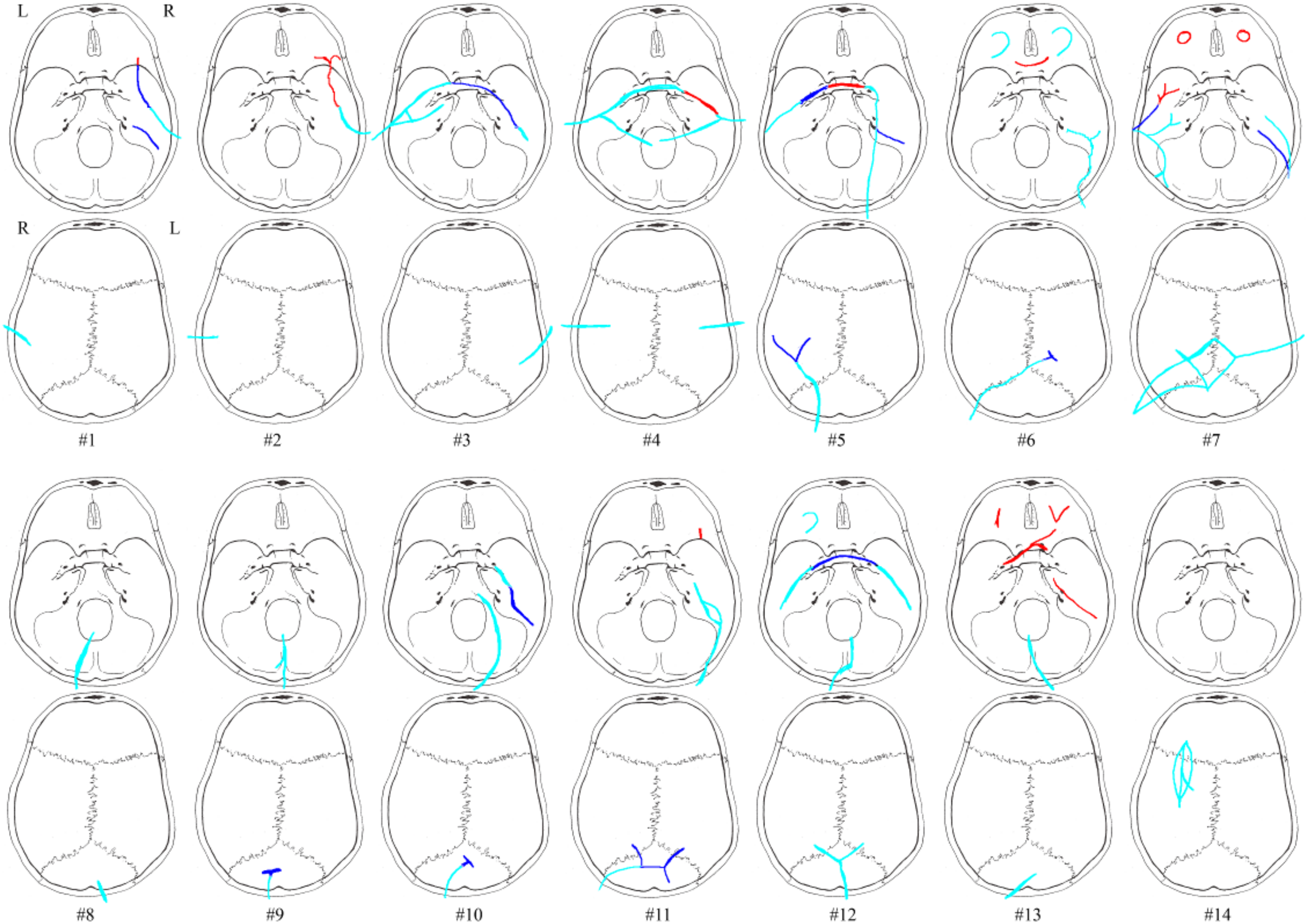


Figure 3.

MPR (right) and MIP (left) coronal images of fractures in the left temporal bone and right great wing of the sphenoid.

The MIP provides a very good overview of the extension of the fractures. The fractures in the temporal bone are indicated by black arrows and the fractures in the great wing of the sphenoid are indicated by white arrows.

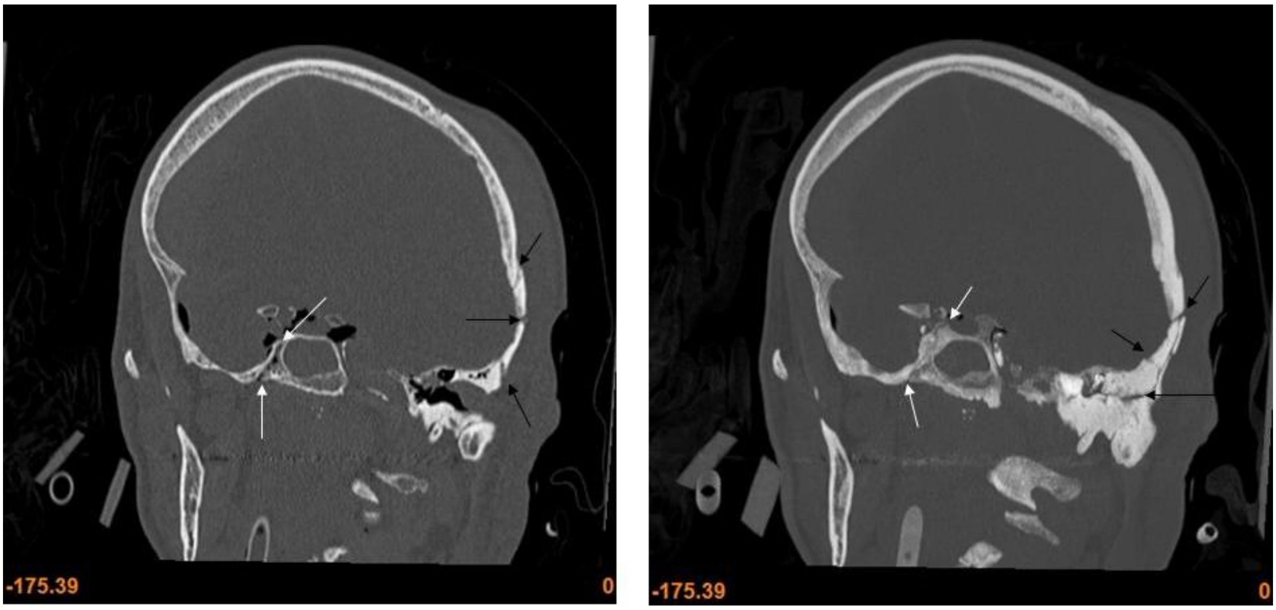
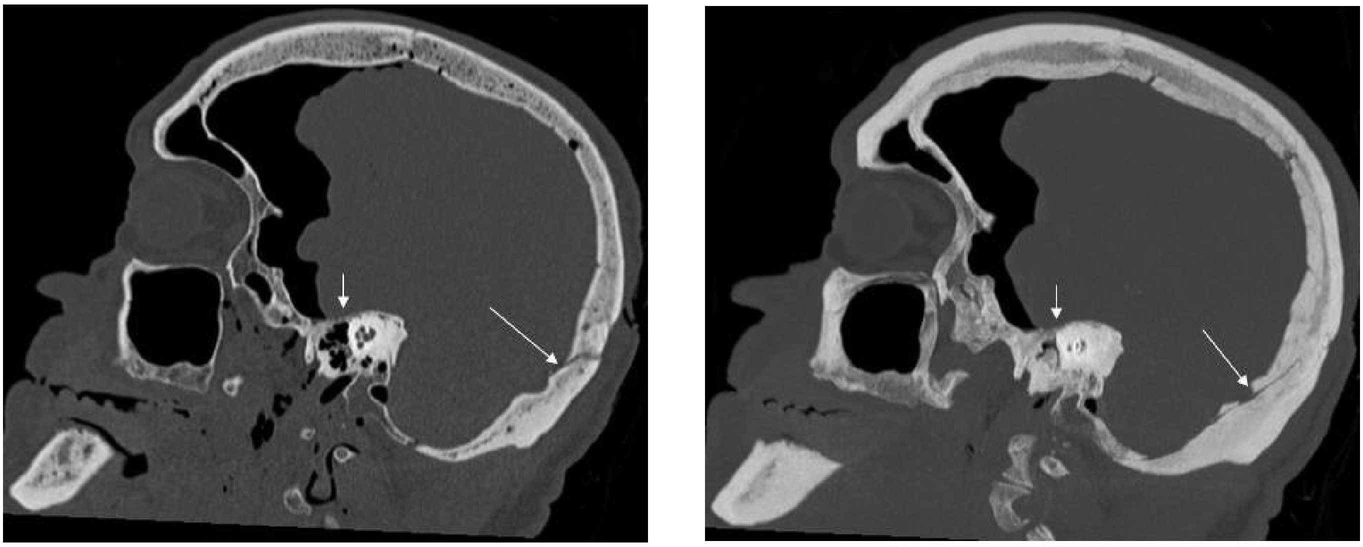


Figure 4.

MPR (right) and MIP (left) sagittal images of fractures in the occipital bone and petrous part of the temporal bone.

The MIP provides an overview of the fractures extension and the hairline fracture in the petrous (short white arrow) and occipital bone (long white arrow).



Tables

Table 1.

Case based number of fractures in the anatomic entities of the neurocranium

Fractures	Base			Vault	Total
	Anterior fossa	Medial fossa	Posterior fossa		
Unilateral	4	5	7	5	21
Bilateral	3	6	1	3	13
Total	7	11	8	8	34

Table 2. Comparison of the digitised fracture length to the fracture length as measured on CT images of the first reading

Case no.	Digitiser (cm)	CT (cm)	Digitiser - CT subtraction sum (cm)	Anatomic localisation of miss
#9	13.4	8.3	5.1	Occipital bone T-shaped hairline fracture
#11	22.2	17.5	4.7	Petrous bone, minor wing of the sphenoid (~1 cm each) and H-shaped fracture in the occiput
#6	20.4	18.1	2.3	Parietal bone (0.6 cm) and petrous bone (1.7 cm)
#1	22.1	10.3	11.8	Petrous bone ~3 cm and the great wing of the sphenoid (~8.8 cm)
#14	6.7 (length) 2.4 (width)	5.8 (length) 1.7 (width)	0.9 (length) 0.7 (width)	Depression fracture of the parietal bone

The fracture of the eyeloft in case no. 6 was not digitised

Table 3. Number of fractures in each bone as diagnosed by autopsy versus CT-scan

Region	Anterior fossa		Medial fossa			Posterior fossa	Vault			Total
Bone	Frontal	Sphenoid	Temporal	Sphenoid	Sphenoid	Occipital	Frontal	Parietal	Temporal	
	Pars orbitalis	Minor wings	Petrous	Greater wings	Sella turcica				Pars squamosa	
Autopsy	7	5	15G	15	4	8	1	12	9	76
1st CT reading	3	0	6	5	2	8	1	9	8	42
2nd CT reading	3[a]	0	11	11	3	8	1	12	9	58

[a]One case with two fractures of the eyeloft did not undergo the second evaluation