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Representation of cerebral bridging veins in infants by postmortem computed tomography

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Abstract

The postmortem diagnosis of shaken baby syndrome, a severe form of child abuse, may be difficult, especially when no other visible signs of significant trauma are obvious. An important finding in shaken baby syndrome is subdural haemorrhage, typically originating from ruptured cerebral bridging veins. Since these are difficult to detect at autopsy, we have developed a special postmortem computed tomographic (PMCT) method to demonstrate the intracranial vein system in infants.

This method is minimally invasive and can be carried out conveniently and quickly on clinical computed tomography (CT) systems. Firstly, a precontrast CT is made of the infant's head, to document the original state. Secondly, contrast fluid is injected manually via fontanel puncture into the superior sagittal sinus, followed by a repeat CT scan. This allows the depiction of even very small vessels of the deep and superficial cerebral veins, especially the bridging veins, without damaging them. Ruptures appear as extravasation of contrast medium, which helps to locate them at autopsy and examine them histologically, whenever necessary.

Keywords: Shaken baby syndrome; Bridging veins; Subdural bleeding; Postmortem computed tomography (PMCT)

1. Introduction

Shaken baby syndrome is a particularly severe form of child abuse. This is typically triggered when a crying baby cannot be comforted and the carer loses patience. The baby is grasped by the arms or round the chest (seldomly by the neck) and violently shaken. While the infant's head is severely thrown back and forth, the head can reach high levels of translational and rotational velocity. The consequences are diffuse axonal injuries (DAI) with brain swelling as well as injuries to the bridging veins with subsequent subdural bleedings [1,2]. In cases with a fast and massive increase of intracranial pressure, the subdural bleedings require comparatively little space.

Shaking can also be combined with direct injury to the head. These direct injuries can occur if, while being shaken, the baby's head is hit against a hard surface, such as a bed, wall, or other object (shaken impact syndrome).

Lethal infantile subdural haematomas in violently shaken infants with a lack of external signs of injury are repeatedly published in forensic and paediatric journals [3–6]. Investigators are frequently confronted with delinquents'

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self-serving declarations, such as the injuries resulted from falls from changing tables or other such minor accidents. As a consequence, it is forensically important to discriminate accidental causes and intentional violence [7–10]. There is, however, no universally valid appraisal procedure to help distinguish between these causes. Whenever several ruptures of bridging veins are detected, intense violence, such as severe shaking, is more likely to be the cause than a minor accident [11].

If the body exhibits no visible external signs of injury, only autopsy may help to exclude the possibility of misinterpretation as sudden infant death syndrome (SIDS). It should also be kept in mind that newborns sometimes suffer subdural bleedings from ruptured bridging veins as a delivery complication. Literature also reports anecdotal cases of foetal subdural haematomas caused by automobile accidents or assaults on the mother [12,13].

As the detection of ruptured bridging veins is difficult, even with established methods, we have developed a postmortem computed tomographic (PMCT) method to demonstrate the intracranial vein system in infants.

2. Current status of established methods

2.1. Standard method of brain removal

The technique used in forensic autopsies of infant brains depends on the age of the infant. In the early infant months, the skull sutures are soft and unossificated, so that a special head dissection method in newborns can be employed. In cases of older infants with suspected head trauma, the Flechsig cut can be used (Werkgartner [14]; Krauland [15]). With both techniques, in order to reduce the risk of artificial ruptures, less traction is applied to the parasagittal bridging veins than with other methods.

2.2. Head dissection in newborns

A common technique for opening the intracranial cavity of newborns is to use a special cut, in order to gain an overview of the tentorium and the falx in its entirety and to be able to discover possible ruptures. The result of this cut looks like the handle of a basket, so in German we talk about the ‘‘Korbhenkelschnitt’’ [17].

The typical procedure after removing the galea aponeurotica is to insert the scalpel into the region of anterior fontanel approximately 1 cm to the side of the midline and then cut the bone and dura with cartilage scissors, 1 cm parallel to the midline, back towards the occipital region. From there the cut is taken along the typical saw-cut line for adults up to the frontal region and then back to the anterior fontanel. If an adequate safety margin to the midline is left, the bridging veins are easily visible under the resulting ‘‘basket handle’’ strip of at least 2 cm (Fig. 1).

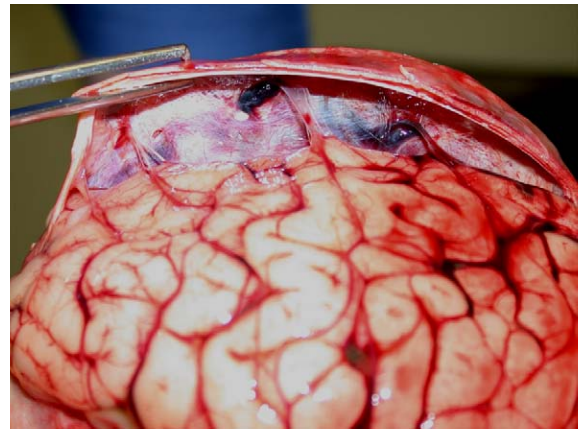

Fig. 1. The ‘‘Korbhenkelschnitt’’. The tweezers lift the rest of the skull and the bridging veins are easily visible under the resulting ‘‘basket handle’’ strip.

The disadvantage of this method is that after cutting the dura the blood runs out of the vascular system, so that the veins to be examined are collapsed.

2.3. Flechsig cut

The Flechsig cut is a special cut through the brain on a horizontal plane in situ before the calvarium is taken off (Werkgartner [14]; Krauland [15]) (Fig. 2). This technique has advantages over the removal of the whole brain: already at dissection it offers a good orientation of the intracranial and intracerebral situation. Moreover, this method reduces the traction to the parasagittal bridging veins. Although it is possible to see ruptured bridging veins of the lower brain surface if the brain is carefully extracted, it is not possible to see the parasagittal veins in the top half of the brain unless it is removed from the calvarium. If there are no particularly strong adhesions, the dura mater can be loosened from the calvarium along with the brain using a special long and curved spatula. The dura is then cut in strips starting from the lateral margin and going up to the parasagittal region in order to avoid damaging the individual veins.

This method however cannot be used if the dura is firmly attached to the bone, as is often the case with infants. In these cases, the bridging veins may be damaged postmortally. It is then difficult to prove vital injuries to bridging veins, in particular when the infant has died shortly afterwards. There does not then appear to be a satisfactory way to prepare the bridging vein ruptures without artificial damage.

2.4. X-ray examination according to Maxeiner

For this method the Flechsig cut is also used. After cutting through the brain on a horizontal plane in situ before the calvarium is taken off, a balloon catheter is placed and blocked in the occipital sagittal sinus and approximately 5–15 ml of contrast medium (barium sulphate solution) are

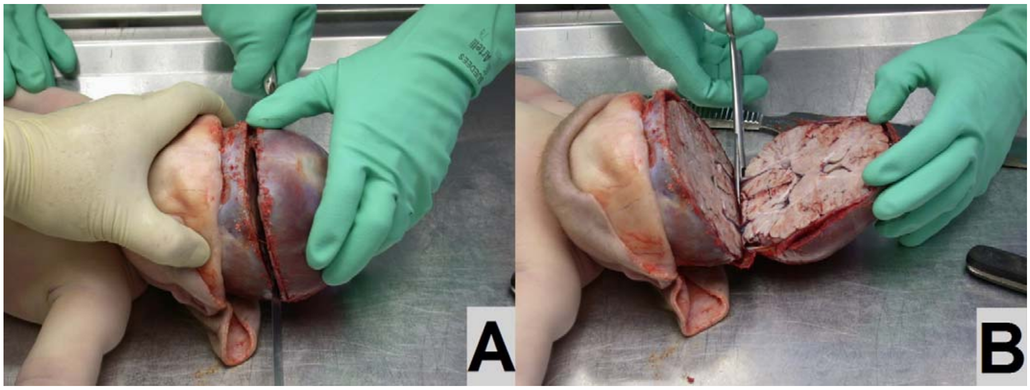

Fig. 2. (A and B) The Flechsig cut through the brain on a horizontal plane in situ before the calvarium is taken off.

instilled. Axially X-rays are thereupon acquired in quick succession [18,19]. On the X-ray images, ruptures are visible as extravasation, so that this method is a further useful examination to autopsy.

The X-ray method has the following disadvantages: firstly, only the upper parasagittal bridging veins are represented radiologically; secondly, the investigator manipulates at the exposed brain; thirdly, the cranium of very young infants with still unossificated skull sutures is very unstable and may easily be damaged during investigation. Finally, the conventional X-rays are merely projection images, with limited sensitivity to small extravasations, and offering poor spatial orientation.

2.5. *Own examination method*

2.5.1. *Computed tomographic representation of cerebral veins*

2.5.1.1. Material. Since the establishment of a computed tomography (CT) scanner (Siemens Somatom Plus-S, Erlangen, Germany) at the Institute of Forensic Medicine in Heidelberg, we have routinely examined by CT the heads of all the deceased delivered to the Institute for forensic autopsy, in order to detect or to exclude injuries. We examined the bodies of infants up to the third completed year of life. To develop the method, the corpses of 11 infants were prepared in the period from December 2003 to February 2005 (age: 2 days to 19 months, sex ratio: 7 males and 4 females, manner of death: 3 natural causes and 2 unnatural causes [battered child syndrome/death by asphyxia] and 6 cases of SIDS. The postmortem interval lay between 12 h and 4.5 days (Table 1)).

2.5.1.2. Method. Firstly, in order to later identify any possible artificial damage caused by this contrast medium examination, the original state was documented by not only acquiring a babygram of the infant's body but also a pre-contrast CT of the head, up to and including the pelvis, slice thickness 3 mm. Then the external inspection followed. As part of this, the head was palpated and the conjunctiva and oral mucosa were examined for bleeding or injury.

In corpses of very young infants with unossificated skull sutures and an unstable cranium, the spiral drill method used in adults [20] was not suitable. The direct way through the cranium was best achieved by fontanel puncture, either

Table 1
Case material

Case	Age (months)	Sex	Cause of death	Postmortem interval (days)
1	7 weeks	F	SIDS	0.48
2	5	M	Rupture of atrial auricle/battered child syndrome	2.79
3	19	M	Putrid bronchitis	3.1
4	10.5	F	Hypoplasty of left coronary artery of heart	1.13
5	10	F	SIDS	3.56
6	3	M	SIDS	2.24
7	2.5	M	SIDS	3.38
8	2 days	M	Asphyxia	1.22
9	2	F	SIDS	2.34
10	3 days	M	Pneumonia	1.56
11	3.5	M	SIDS	4.48

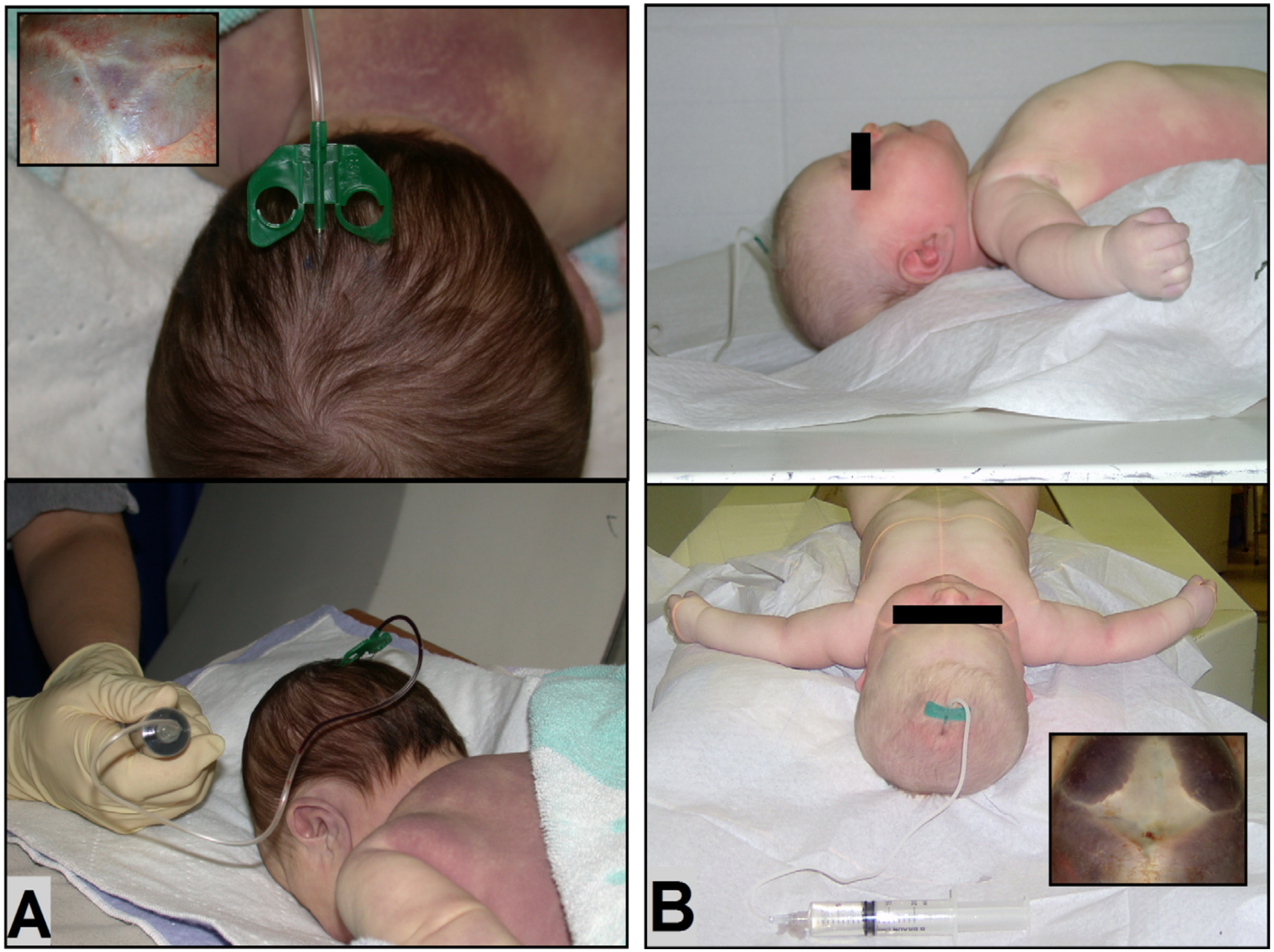

Fig. 3. (A) Puncture of the posterior fontanel in prone position and (B) puncture of the anterior fontanel in supine position.

Table 2
Investigation procedure and evaluation of cerebral vein filling

Case	Fontanel	Puncture position	Puncture direction	Contrast medium (CM) in ml ($CM:H_2O$)	Position changed	Reinjection in ml ($CM:H_2O$)	Position changed	Failed puncture	Filling of cranial sinuses	Filling of superficial cerebral veins	Filling of deep cerebral veins
1	Posterior	Prone	Frontal	20 (1:0)	No				++	++	++
2	Posterior	Prone	Frontal	40 (1:0)	No				++	++	++
3	Anterior	Prone	Dorsal	35 (2:1)	No				+	+	+
						20 (2:1)	Yes		++	++	++
4	Anterior	Supine	Dorsal	60 (1:3)	No			Yes	−	−	−
5	Anterior	Supine	Dorsal	20 (1:0)	No	10 (1:0) during scan			+	−	−
					Yes	10 (1:0)			++	++	++
6	Anterior	Prone	Dorsal	30 (2:1)	No	35 (2:1) during scan, perfusor (100 ml/h)			++	+	++
7	Anterior	Supine	Frontal	5 (1:0)	No				++	+	−
8	Anterior	Supine	Frontal	14 (1:0)	No			Yes	++	−	−
9	Anterior	Prone	Dorsal	15 (1:0)	No			Yes	−	−	−
						Ø	Yes		−	−	−
10	Anterior	Prone	Dorsal	20 (1:10)	Yes	10 (1:10)			+	+	++
11	Anterior	Prone	Dorsal	15 (1:3)	No				++	+	++
					Yes	10 (1:3)			++	++	++

(++) vessel filled completely; (+) vessel filled in sections; (−) vessel not filled.

through the smaller posterior triangular or the bigger anterior quadrangular fontanel.

The posterior fontanel is closed in the first 3 months postpartum, so that in older infants the anterior fontanel has to be used, which closes much later (in 50% of the infants between the 9th and 18th month of life and at the latest between the 24th and 27th month of life) [21]. Unlike clinical fontanel puncture, care must be taken with post-mortem fontanel puncture that only the sinus sagittalis superior is punctured and not the subdural space.

To investigate the optimal distribution of contrast medium, different body positions and puncture directions were tested. Depending on the infant's age and anatomical condition, the anterior or the posterior fontanel was punctured. The posterior fontanel was punctured in two cases at a slant to frontal, into and along the sinus sagittalis superior, with the infant in prone position. The anterior fontanel was punctured in five cases in prone and in four cases in supine position, in which the needle was inserted into and along the sinus in seven cases to dorsal and in two cases to frontal (Fig. 3; Table 2).

We employed a 21-G-needle (Butterfly BRAUN®). The Butterfly was connected to a syringe containing iodine-based contrast medium (e.g. Ultravist 300® or Imeron 300®) and the air evacuated from the system. In order to delay the contrast fluid's flowing off via the jugular veins, the head was punctured in a head-down position. In order to avoid a subdural or subarachnoidal puncture, the needle was inserted under aspiration as tangentially as possible, through the anterior or posterior fontanel membrane, at the bone-edge in the opposite direction to the membrane and along the sagittal sinus. As soon as the firm puncture resistance relaxed and blood could be aspirated, the needle was not inserted any further, leaving 1–1.5 cm of the 2 cm long needle still visible. By blood aspiration the correct needle position was checked and blood was extracted for chemical–toxicological examination (Fig. 3A). A water-soluble contrast agent was then injected manually with a slow flow of 1 ml/s in different grades of dilution using this injection system. Depending on the infant's age and head size, 5–65 ml contrast fluid was injected. Subsequently CT scans of the head with thin slice thickness were acquired (Fig. 4).

3. Results

In all 11 cases, we successfully punctured and entered the sinus sagittalis superior. In three of these cases, however, we penetrated the sinus resulting in a needle's entrance as well as an exit hole in the sinus wall. In these cases, contrast fluid leaked out of the needle's exit hole, directly into the subdural or subarachnoidal space, so that the vessel filling was insufficient. These artificial holes could be detected at autopsy. The failed punctures showed the importance of a proper puncture technique, inserting the needle under

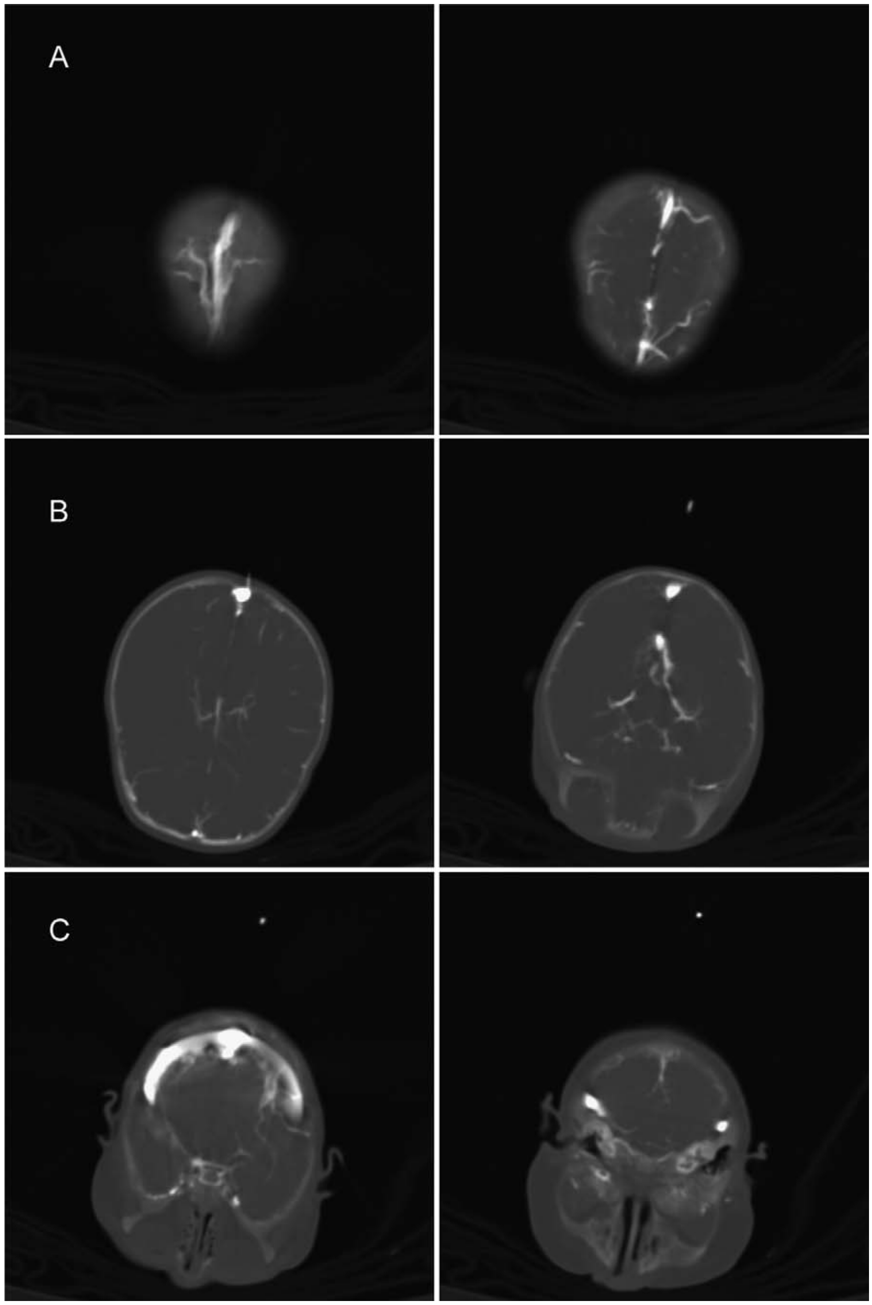

Fig. 4. CT images of the contrast fluid filled sinus sagittalis superior with upper and lower bridging veins (A), deep cerebral veins (B) and sinus transversus and jugular veins (C).

aspiration as tangentially as possible through the fontanel membrane at the bone-edge.

In order to evaluate the contrast fluid filling in the CT image, the cerebral veins were divided into three groups (first group: cranial sinuses; second group: superficial cerebral veins, including the bridging veins; third group: deep cerebral veins) and the degree of vessel filling was judged in three grades (Table 2).

In 8 of our 11 cases, a good contrast fluid filling was reached, in order to represent even very small vessels of the cerebral veins, especially the upper and the lower bridging veins without damaging them (Fig. 4). The contrast agent could be injected in prone as well as in supine position, with similarly good results.

In three cases with an initially less successful filling, contrast fluid was reinjected and the bodies were turned over. Thus in all cases, with the correct needle position, an improved vessel filling was achieved.

In one of the corpses, there was a leakage of contrast fluid other than inside the cranium, i.e., into the pericardial sac. However, intrapericardial fluid with blood's density was already visible on the precontrast CT, so this leakage was not artificial, but, as found at autopsy, due to a preexistent rupture of atrial auricle.

In three other cases contrast medium was seen in the left atrium of heart and in the pulmonary veins and in two of these, in the descending aorta additionally. Explanations for these findings found during autopsy were a patent foramen ovale and a patent ductus arteriosus.

For this postmortem computed tomography study, water-soluble contrast agents containing iodine were preferred to barium sulphate which was not radiopaque enough. Owing to a lack of circulation, the dilution in the blood of contrast medium was highly reduced, so the contrast fluid was diluted prior to injection (dilution grade contrast medium:H_2O, 1:3) in order to reduce high-contrast artefacts.

We found that using a single detector helical CT scanner, spiral scans were the best option for this contrast medium examination. A spiral scan is a continuous acquisition of data from an entire anatomic volume with simultaneous table feed. Such a fast technique was necessary because the contrast fluid flowed off via the jugular veins even when the corpse was in a Trendelenburg position and consequently the optimal contrast fluid filling did not last long. Multi-detector CT scanners would provide even shorter scan times, but, owing to high costs, are not widely distributed for postmortem studies.

4. Discussion

Today there is a lively discussion on whether PMCT could ever completely replace the conventional forensic autopsy as the ''golden standard'' of forensic medical estimate. The Virtopsy® research team in Bern (Switzerland) opened new horizons in forensic medicine based on their feasibility studies about virtual autopsy by postmortem multislice CT and magnetic resonance imaging (MRI). Their aim is to establish an observer independent, objective and reproducible forensic assessment method using modern imaging technology, possibly leading to a minimally invasive virtual forensic autopsy [22,23]. They additionally practise experimental studies, and have just recently presented a minimally invasive multislice CT angiography technique via the right femoral artery, that visualizes the human arterial system including intracranial and coronary arteries. Using this angiography technique, vascular pathologies, such as calcification, stenosis and injury can be detected [24].

The representation of cerebral veins by PMCT is a technique that assists, simplifies and improves the subsequent autopsy in the sense of a ''computer-assisted autopsy'' (CAA). It allows during head dissection, on the one hand, a specified preparation of the injured vein, and on the other hand, a reliable differentiation between intravital injuries and artificial damage. This means that the CT method, as well as the X-ray method, is combined with an established method of brain removal, such as head dissection in newborns, the Flechsig cut or other head dissection methods. However, the CT method has substantial advantages over the X-ray method.

The most important advantage is the reduction of the artificial damage by keeping the skull intact; only a minimally invasive fontanel puncture is made. In the X-ray method in contrast, the skull is always opened by Flechsig cut. This procedure has a high risk of artificial injuries to the head and vessels because of the instability of the baby's cranium and because of the strong traction to cerebral veins.

Compared to the X-ray method, where only the upper parasagittal bridging veins are represented, the CT method demonstrates both the upper and the lower bridging veins, and so demonstrates the whole intracranial vein system. On CT images injuries to all bridging veins are visible as extravasation, so that ruptures can be pinpointed. A specified preparation of the injured vein including histological examination can follow in the subsequent autopsy.

An obvious advantage of CT is that it is 3D, which simplifies the spatial orientation and permits secondary 3D reconstructions using appropriate tools [25,26] (Fig. 5).

Moreover, both methods are easily and quickly carried out (time of CT method including positioning, puncture,

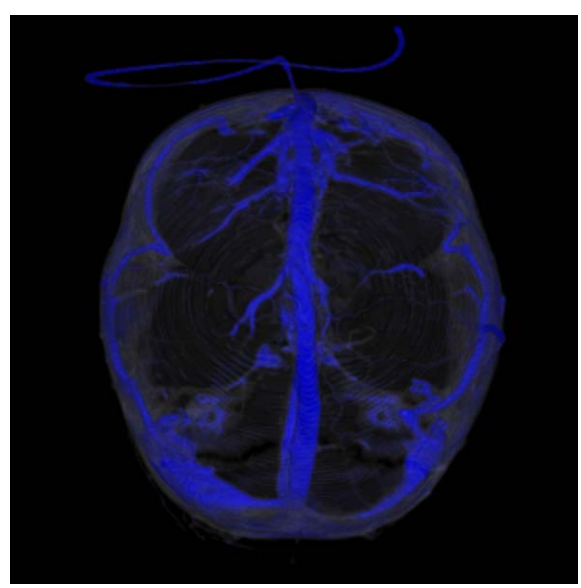

Fig. 5. 3D visualisation of the cerebral vein system by Volume Rendering Technique (Leonardo®).

injection, scan time and image reconstruction: about 30 min).

The disadvantage of the CT method compared to the X-ray method, is that many institutes of forensic medicine do not have their own CT scanner in addition to their own X-ray apparatus and therefore rely on external clinical scanners. Furthermore, CT scanners require qualified personnel to operate them. This situation should be no obstacle to the implementation of the CT method. Because of the baby's size and the method's minimal invasiveness and quick feasibility, it would be realistic to employ clinical CT scanners.

5. Conclusions

The postmortem diagnosis of shaken baby syndrome may be difficult, especially when no other visible signs of significant trauma are obvious. An important finding in shaken baby syndrome is subdural haemorrhage, typically originating from ruptured cerebral bridging veins. However, the representation of bridging veins at autopsy is difficult.

The postmortem CT method to demonstrate the intracranial vein system in infants has significant advantages over the X-ray method, in particular that only a minimally invasive procedure on the intact skull is necessary, and that the whole intracranial vein system, including even very small vessels of the deep and superficial cerebral veins, especially the bridging veins, can be examined without damaging them. Another advantage is the CT method's three-dimensionality with optimal pinpointing of anatomical structures and the possibility of 3D visualisation [25,26] (Fig. 5). Moreover, this method is easily and quickly carried out.

The representation of bridging veins by PMCT is thus a further useful examination method to autopsy (computer-assisted autopsy).

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