ORIGINAL PAPER/*ARTYKUŁ ORYGINALNY*

Feasibility of flat panel detector computed tomography for position assessment of external ventricular drainage

Możliwość zastosowania tomografii komputerowej z płaskim detektorem w ocenie umiejscowienia zewnętrznego drenażu komorowego

Philipp von Gottberg[1], Marios Psychogios[1], Gunther Schuetze[1], Joseph Cohnen[1], Paul Zwaka[2], Michael Knauth[1], Peter Schramm[1]

[1]Department of Neuroradiology, Universitätsmedizin Göttingen, Germany
[2]Department of Diagnostic Radiology, Universitätsmedizin Göttingen, Germany

Neurologia i Neurochirurgia Polska 2013; 47, 1: 32-42
DOI: 10.5114/ninp.2013.32996

Abstract

Background and purpose: New angiographic devices with flat panel detectors allow cross-sectional imaging within the angiographic suite. In patients receiving external ventricular drainage (EVD) to manage hydrocephalus following subarachnoid haemorrhage (SAH), these may help evaluating the position of an EVD without moving the patient to a conventional computed tomography (CT) scanner. It could facilitate patients' management in a life-threatening status. This study therefore compares conventional CT with post-interventional flat panel detector angiographic CT (FDCT) referring to the determinability of an accurate EVD position.
Material and methods: Twenty patients with SAH received FDCT and conventional CT for primary assessment after EVD insertion. Three single-blinded raters compared both modalities and evaluated the image sufficiency for determining the EVD position, EVD tip, intracranial course and whether a contorted drainage tube could be detected.
Results: FDCT was sufficient to detect a correct EVD position in 82.5% of the cases vs. 100% in conventional CT. Regarding the EVD tip, FDCT delivered at least 'good' results in 82.5% vs. 95% in conventional CT data. Determining the EVD intracranial course, FDCT provided at least 'good' data in 92.5% vs. 100% in conventional CT. For detecting tube contortion, FDCT provided at least 'good' results in 70% vs. 98% in conventional CT.

Streszczenie

Wstęp i cel pracy: Nowoczesne systemy angiograficzne sprzężone z płaskimi detektorami umożliwiają obrazowanie warstwowe już w sali zabiegowej. U chorych leczonych za pomocą zewnętrznego drenażu komorowego z powodu wodogłowia w następstwie krwawienia podpajęczynówkowego obrazowanie pozwala na doraźną ocenę położenia drenu bez konieczności wykonywania tradycyjnej tomografii komputerowej (TK). Metoda ta ułatwia postępowanie z chorym w stanie zagrożenia życia. Porównano zgodność obrazów otrzymanych za pomocą tradycyjnej TK z angiografią TK (angio-TK) sprzężoną z płaskim detektorem w ocenie prawidłowego położenia drenu.
Materiał i metody: U 20 chorych z krwotokiem podpajęczynówkowym bezpośrednio po założeniu zewnętrznego drenażu komorowego wykonano tradycyjną TK oraz badanie angio-TK z użyciem płaskiego detektora. Trzech badaczy niezależnie oceniło otrzymane wyniki dotyczące położenia drenu, jego końcówki i przebiegu wewnątrzczaszkowego.
Wyniki: Angio-TK sprzężona z płaskim detektorem pozwoliła na ustalenie prawidłowego położenia drenu w 82,5% przypadków w porównaniu ze 100-procentową dokładnością tradycyjnej TK. Pozycję końcówki drenu zlokalizowano w 82,5% badań za pomocą angio-TK z płaskim detektorem i w 95% badań za pomocą tradycyjnej TK. Wewnątrzczaszkowy przebieg drenu angiograficznie uznano za wiarygodny w 92,5%

Correspondence address: Dr med. Philipp von Gottberg, Department of Neuroradiology, Universitätsmedizin Göttingen, Robert-Koch-Str. 40, 37099 Goettingen, Germany, e-mail: p.vongottberg@med.uni-goettingen.de
Received: 21.11.2011; accepted: 13.06.2012

Conclusions: FDCT is a promising method to determine the correct position of an EVD in patients with SAH. Following a neuroradiological intervention, it facilitates the patients' management and renders additional transfers to conventional CT unnecessary in the majority of cases.

Key words: flat panel detector CT, external ventricular drainage, hydrocephalus, cerebral angiography.

badań angio-TK przy 100-procentowej zgodności w tradycyjnej TK. Natomiast zagięcie drenu znaleziono odpowiednio w 70% i 98% badań.
Wnioski: Angio-TK sprzężona z płaskim detektorem jest przydatna w lokalizacji zewnętrznego drenażu komorowego u chorych z krwotokiem podpajęczynówkowym. Przeprowadzona w trakcie interwencji upraszcza postępowanie i sprawia, że wykonanie u chorego tradycyjnej TK jest najczęściej zbędne. Jednocześnie wykazano, że angiografia sprzężona z płaskim detektorem nie może zastąpić tradycyjnej TK w ocenie przebiegu krwawienia podpajęczynówkowego.

Słowa kluczowe: TK z płaskim detektorem, zewnętrzny drenaż komorowy, wodogłowie, angiografia mózgowa.

Introduction

In patients suffering from subarachnoid haemorrhage (SAH) due to the rupture of an intracranial aneurysm, increasing intracranial pressure and decreasing cerebral perfusion pressure are common complications caused by multiple pathological mechanisms [1-5]. Therefore, constant monitoring and assessing of the increased intracranial pressure and cerebral perfusion pressure is mandatory. It is achieved through application of an external ventricular drainage (EVD).

Another common complication in these patients is development of hydrocephalus. About 16-34% of patients with SAH are suspected to develop hydrocephalus [6-9], which subsequently leads to worsening of the neurological status in more than 80% [10]. EVD is applied as a common therapy to manage this complication [11]. EVD has proven to be beneficial for more than 70% of patients showing neurological symptoms due to hydrocephalus caused by SAH [12].

The accuracy of the EVD position is usually assessed with computed tomography (CT) of the head. Especially in free-hand insertion of EVD, its accuracy can be inappropriate and may require revision in about 40% [13].

Catheter-based intra-arterial digital subtracted angiography (DSA) is commonly used for detailed diagnosis of aneurysms in patients with SAH [14]. In the past 5 years, a new generation of flat panel angiographic suites has been introduced [15]. This new generation of detectors allows cross-sectional imaging within the DSA suite by performing 3D tomographic imaging of the brain and skull in isotropic spatial resolution of 0.5 mm or less (flat panel detector CT, FDCT) [16]. The EVD X-ray absorption and amount of Hounsfield units (HU) is close to bone (between 800 and 1200 HU), making it easy to differentiate it from brain parenchyma. Prior research has also proven FDCT to be reliable for an initial diagnosis of intracranial bleeding or hydrocephalus [17,18].

Patients with the diagnosis of SAH on initial conventional CT will often undergo DSA for better depiction of the vascular malformations, as DSA has a very high spatial resolution and provides further temporal information [19,20]. In some departments, DSA is carried out under conditions similar to the operating room. Therefore, EVD insertion can already be carried out at this point, if necessary. During DSA, an FDCT can be performed to evaluate the position of the EVD without having to move the patient to a conventional CT scanner. This would optimize the patient's management, since a patient in critical or highly life-threatening status due to the SAH may be difficult to manage.

Hence, the goal of this study was to compare conventional brain CT imaging with post-interventional FDCT imaging referring to the determinability of an accurate EVD position.

Material and methods

Twenty patients suffering from acute SAH (9 male, 11 female) aged between 24 and 88 years (median: 61) were included in this study (see Table 1 for demographic details). All patients underwent FDCT immediately following neuroradiological diagnostic angiography or intervention, after insertion of an EVD (External CSF Drainage, Dispomedica® GmbH, Hamburg/Germany). Further, all patients received a conventional CT of the head within 72 hours. The EVD was inserted immediately prior to the angiography or intervention by an experienced neurosurgeon. The application of EVD

Table 1. Demographic details of studied patients

Number	Age	Sex	Symptoms	Intraventricular haemorrhage	Initial diagnosis	Treatment	Complications
1	73	Male	Unconsciousness following sudden headache	Yes	SAH H&H 4, supraclinoid aneurysm	Coil embolisation	Initial hydrocephalus
2	79	Male	Unconsciousness of unknown cause	No	SAH H&H 5, AComA aneurysm	Coil embolisation	Bifrontal infarction
3	24	Female	Sudden headache	No	SAH H&H 2, parenchymal haemorrhage. Arterio-venous malformation and ACA aneurysm	Coil embolisation	No major complications
4	76	Female	Unconsciousness of unknown cause	Yes	SAH H&H 4, ACA aneurysm	Coil embolisation	Initial hydrocephalus
5	49	Female	Sudden headache	Yes	SAH H&H 1, AComA aneurysm	Coil embolisation	No major complications
6	33	Male	Unconsciousness of unknown cause	No	SAH H&H 4, MCA aneurysm	Coil embolisation	Hemicraniectomy following vasospasm and brain oedema
7	88	Male	Unconsciousness following sudden headache	Yes	SAH H&H 5, distal carotid aneurysm	Clip occlusion and coil embolisation	Drug-responsive brain oedema
8	75	Female	Unconsciousness following sudden headache	Yes	SAH H&H 5, basilar aneurysm	Coil embolisation	No major complications
9	66	Male	Unconsciousness of unknown cause	Yes	SAH H&H 4 of unknown cause	Medical treatment of brain oedema	Drug-responsive brain oedema
10	61	Female	Unconsciousness of unknown cause	No	SAH H&H 5, distal carotid aneurysm	Coil embolisation	Vasospasm
11	67	Male	Unconsciousness of unknown cause	Yes	SAH H&H 5, fusiform basilar aneurysm	Intravascular stent covering	Mesencephalic infarction
12	70	Male	Unconsciousness of unknown cause	Yes	SAH H&H 5, AComA aneurysm	Coil embolisation	Initial hydrocephalus
13	40	Female	Unconsciousness of unknown cause	No	SAH H&H 5, basilar aneurysm	Coil embolisation	Drug-responsive brain oedema, infarction
14	62	Female	Sudden headache	No	SAH H&H 3, several intradural aneurysms	Clip occlusion and coil embolisation	Vasospasm
15	55	Female	Unconsciousness following sudden headache	No	SAH H&H 5, AComA and MCA aneurysms	Coil embolisation	No major complications
16	68	Male	Sudden headache	No	SAH H&H 4, PComA and MCA aneurysms	Clip occlusion and coil embolisation	No major complications
17	42	Female	Sudden headache	Yes	SAH H&H 2, basilar aneurysm	Coil embolisation	No major complications
18	59	Female	Unconsciousness of unknown cause	Yes	SAH H&H 5, MCA aneurysm	Coil embolisation	Initial brain oedema, infarction
19	72	Female	Sudden unconsciousness	Yes	SAH H&H 4, AComA aneurysm	Clip occlusion and coil embolisation	No major complications
20	59	Male	Unconsciousness of unknown cause	Yes	SAH H&H 5, AComA aneurysm	Coil embolisation	Infarction, drug-responsive brain oedema

SAH – subarachnoid haemorrhage, H&H – Hunt and Hess score, AComA – anterior communicating artery, ACA – anterior cerebral artery, MCA – medial cerebral artery, PComA – posterior communicating artery was of preventive kind in 16 of the cases, and 4 patients presented with initial hydrocephalus. The indication for the preventive kind of EVD was derived from the diagnosis of SAH in the initial conventional CT.

For DSA and FDCT, we used a biplane angiography system with flat panel detectors (Axiom Artis dBA angiography system, Siemens AG, Forchheim, Germany). For FDCT acquisition, we chose the commercial DynaCT™ program with the following settings: 20 seconds rotation time, 538 projections, 220° total angle, weighted CT dose index approximately 35 mGy (manufacturer information), detector of 30 cm × 40 cm size that allows the reconstruction of a non-truncated volume of approximately 22 cm (in-plane) and 16 cm (in z-direction). These settings were chosen as a result of prior research and had already been proven expedient [9,10]. Tube voltage ranged between 50 and 125 kV, generator power was variable, but self-regulated and self-controlled by the shutter priority [21]. For further evaluation, the volume data sets were processed into 20 modified axial slices, parallel to the canthomeatal plane and analogous to the conventional cranial conventional CT (skull base slice thickness, 4 mm and cerebrum, 6 mm). Window levels were set to a standardized value when being presented to the investigators. When going through the score tables, however, they were allowed to choose their preferred window values on the PACS workstation.

We compared FDCT with conventional CT, because conventional CT resembles the standard, established modality in clinical tomographic follow-up imaging and thus was assumed to have an accuracy high enough to be considered referential. Non-enhanced CT (NECT) images were acquired using a 128-Multi-Slice CT (Somatom Definition AS+, Siemens AG, Forchheim, Germany). Approximately 20 slices were acquired parallel to the canthomeatal plane. Slice thickness was 4 mm for the skull base and 6 mm for the cerebrum. The Pitch factor in conventional CT examinations was set to 0.55 mm/rotation. Convolution kernel was H31s (soft tissue). Tube voltage was 120 kV, generator power ranged from 200 to 275 mA.

Three single-blinded raters (two experienced radiologists, one of them specialized in neuroradiology [investigator #1], and one novice radiologist [investigator #3]), compared both FDCT and conventional CT being displayed as axial multiplanar reconstructions. See Figs. 1-3 for examples of conventional CT images and FDCT images used in this study, displaying conventional CT on the left and FDCT on the right in the same patients. The chosen selection includes a case with craniotomy following infarction due to vasospasm and the development of malign brain oedema. Some patients developed complications of an SAH or its treatment as mentioned in Table 1. These patients were however not excluded from this study to evaluate the FDCT method under circumstances of daily routine.

The following points had to be dealt with by the raters: 1) determinability of the EVD tip; 2) determinability of the EVD intracranial course; 3) detectability of a contorted EVD, and 4) image quality sufficient to decide whether the EVD was in an accurate or inaccurate position.

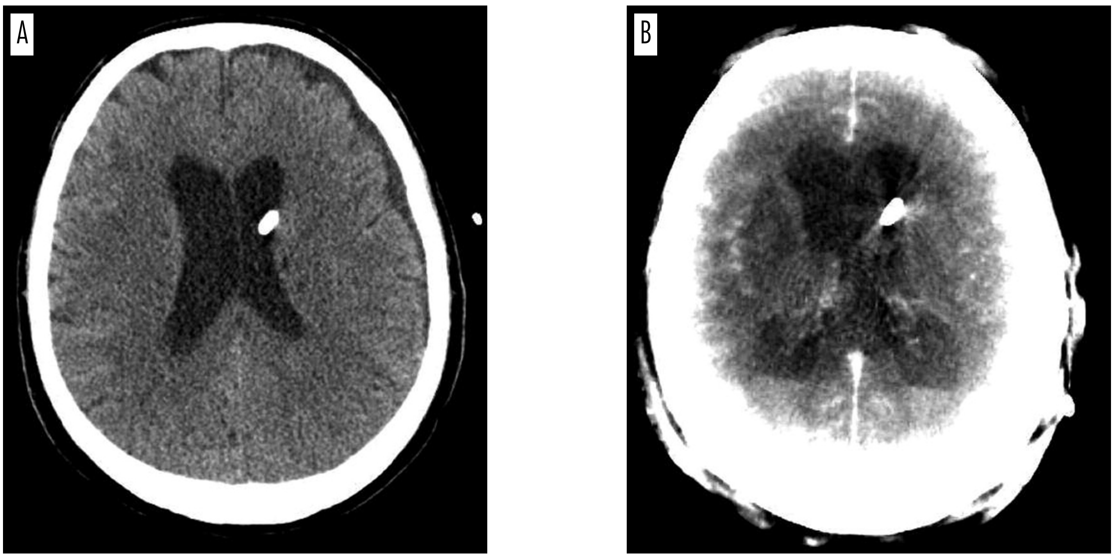

Fig. 1. Example of NECT- (A) and FDCT-imaging (B)

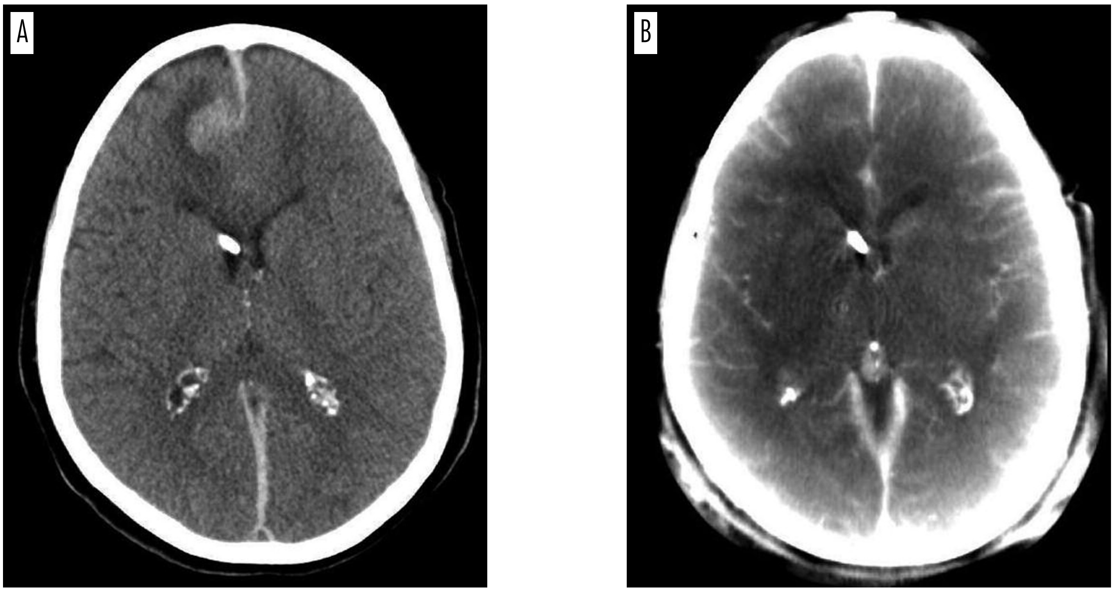

Fig. 2. Example of NECT- (A) and FDCT-imaging (B)

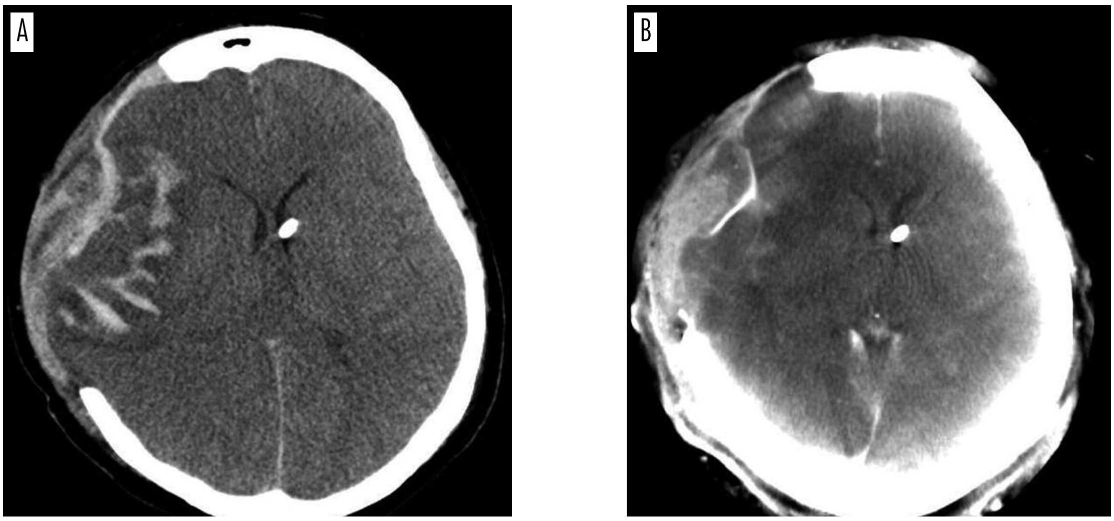

Fig. 3. Example of NECT- (A) and FDCT-imaging (B)

For points 1-3, the investigating radiologists could give a subjective ranking score of 1-5 for each examination (1 – 'very good', 2 – 'good', 3 – 'satisfactory', 4 – 'poor', 5 – 'insufficient'). For point 4, the only answers to choose were 'Yes' or 'No'.

For statistical analysis, inter-rater reliability was calculated following the formula:

$$C_R = \frac{3 \times C_m}{C_1 + C_2 + C_3}$$

C_m marks the matching results ('encodings') in respect of order; C_1-C_3 marks the number of results by investigator #1 to #3. The inter-rater reliability in this study therefore only respects exact matches; it does not respect the distance of differing values.

The score values were added up referring to item, modality and investigator. We carried out graphical interpretations for a better evaluation of the results.

Results

All images could be analysed, and the general image quality was sufficient in all cases.

Table 2. Inter-rater reliability among all investigators and between experienced investigators only

Item	All investigators		Experienced investigators only (investigators #1 and #2)	
	FDCT	Conventional CT	FDCT	Conventional CT
Determinability of EVD tip	0.217	0.467	0.2	0.35
Determinability of EVD intracranial course	0.333	0.7	0.6	0.85
Detectability of contorted drainage tube	0.217	0.383	0.45	0.2
Image quality sufficient to decide whether the EVD was in accurate or inaccurate position	0.633	1	0.85	1
	Total	0.494	Total	0.563

EVD – external ventricular drainage, CT – computed tomography, FDCT – flat panel detector CT

Inter-rater reliability

Table 2 shows the inter-rater reliability in total and between the two experienced radiologists (investigators #1 and #2). With a total of 0.494 for all three investigators, it can be considered as moderate agreement [22].

Image quality sufficient to determine a correct EVD position

Figure 4 displays the investigators' comments regarding the point whether image quality was sufficient to determine the accurate position of the EVD, and Table 3 displays the results in detail. In total, 70% of the FDCT data was found to be sufficient regarding this point, versus 100% of the conventional CT data.

Determining the EVD tip and intracranial course

Table 3 shows the raters' findings regarding the points 'EVD tip' and 'EVD intracranial course' in detail.

In total, 65% of the FDCT images were rated 'very good' or 'good' for determining the EVD tip. Less than 4% (3.6%) were rated 'insufficient'. In conventional CT imaging, 83.3% of the images were rated at least 'good' regarding this point. None was seen to be insufficient (Fig. 5).

Referring to the intracranial course, a total of 83.3% among the FDCT images were rated to be at least 'good' and 1.7% were assessed as 'insufficient'. Conventional CT was found to be of at least 'good' image quality regarding this point in 100% (Fig. 6).

Detectability of a contorted drainage tube

Table 4 shows the investigators' findings in detail. Seventy percent of the FDCT images were found to be of at least 'good' quality, with no 'insufficient' findings. Conventional CT was rated at least 'good' in 98.3% referring to this point, also without any images rated 'insufficient' (see Fig. 7).

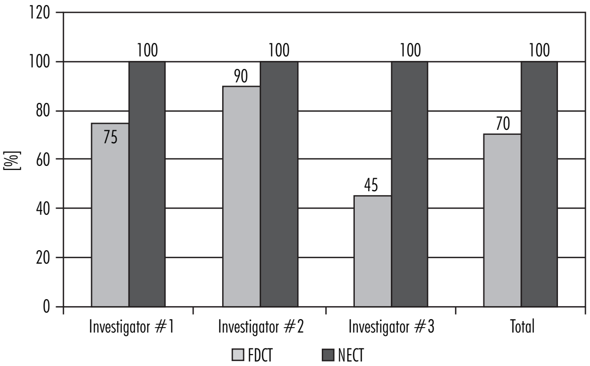

Fig. 4. Image quality sufficient for determining correct EVD position

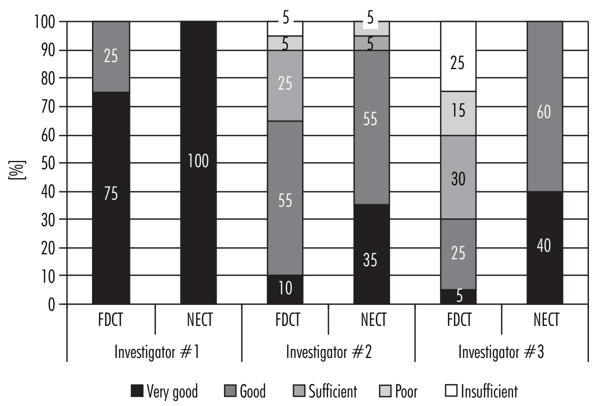

Fig. 5. Determinability of the EVD's tip

Table 3. Investigators' results referring to determining the external ventricular drainage (EVD) tip, the intracranial course of EVD and the accurate position of EVD

	Investigator #1						Investigator #2						Investigator #3					
Exam. Number	Determination of EVD tip		EVD intracranial course		Accurate EVD position can be determined		Determination of EVD tip		EVD intracranial course		Accurate EVD position can be determined		Determination of EVD tip		EVD intracranial course		Accurate EVD position can be determined	
	FDCT	CCT	FDCT	CCT	FDCT	CCT	FDCT	CCT	FDCT	CCT	FDCT	CCT	FDCT	CCT	FDCT	CCT	FDCT	CCT
1	1	1	1	1	Yes	Yes	2	3	1	1	Yes	Yes	1	1	2	1	Yes	Yes
2	1	1	1	1	Yes	Yes	2	2	1	1	Yes	Yes	3	2	2	2	No	Yes
3	1	1	1	1	Yes	Yes	3	1	2	1	Yes	Yes	3	2	2	2	No	Yes
4	1	1	1	1	Yes	Yes	2	2	1	1	Yes	Yes	3	2	2	2	Yes	Yes
5	1	1	1	1	Yes	Yes	2	4	1	2	Yes	Yes	5	1	2	1	No	Yes
6	2	1	1	1	No	Yes	5	2	3	2	No	Yes	3	2	3	1	Yes	Yes
7	1	1	1	1	Yes	Yes	2	2	1	1	Yes	Yes	2	2	2	2	Yes	Yes
8	1	1	1	1	Yes	Yes	2	2	1	1	Yes	Yes	3	1	2	1	Yes	Yes
9	1	1	1	1	Yes	Yes	1	1	1	1	Yes	Yes	5	1	3	1	No	Yes
10	1	1	1	1	Yes	Yes	1	1	1	1	Yes	Yes	3	2	2	1	No	Yes
11	2	1	2	1	No	Yes	3	2	2	1	Yes	Yes	5	2	3	1	No	Yes
12	1	1	1	1	No	Yes	4	2	2	1	No	Yes	4	2	2	1	No	Yes
13	1	1	1	1	Yes	Yes	3	2	2	1	Yes	Yes	4	1	3	1	No	Yes
14	2	1	1	1	Yes	Yes	2	2	1	1	Yes	Yes	2	2	1	1	Yes	Yes
15	1	1	1	1	Yes	Yes	2	1	2	1	Yes	Yes	2	1	2	1	Yes	Yes
16	2	1	2	1	No	Yes	2	2	2	1	Yes	Yes	4	2	4	2	No	Yes
17	1	1	1	1	Yes	Yes	2	1	3	1	Yes	Yes	2	1	2	1	Yes	Yes
18	1	1	1	1	Yes	Yes	2	1	2	1	Yes	Yes	2	1	2	1	Yes	Yes
19	2	1	2	1	No	Yes	3	1	2	1	Yes	Yes	5	2	3	2	No	Yes
20	1	1	1	1	Yes	Yes	3	2	3	2	Yes	Yes	5	2	3	1	No	Yes

CCT – conventional computed tomography, FDCT – flat panel detector computed tomography

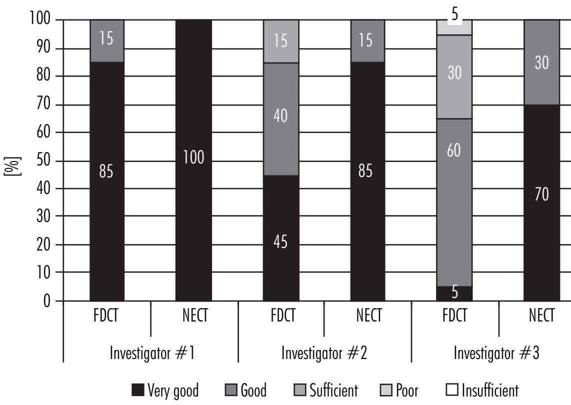

Fig. 6. EVD's intracranial course

Discussion

FDCT provides cross-sectional images and enables immediate detection of haemorrhage or hydrocephalus immediately after neuroendovascular procedures within the angiography suite [16,17].

When it comes to the evaluation of an EVD, referring to the results shown above, conventional CT as the current standard is more valid to determine both the position of the tip and the intracranial course. In direct comparison, conventional CT also seems to be more reliable regarding the provided information about the accurate position of the EVD tip or a possible complication fol-

Table 4. Investigators' results referring to the detection of a contorted external ventricular drainage tube

Examination number	Investigator #1		Investigator #2		Investigator #3	
	FDCT	Conventional CT	FDCT	Conventional CT	FDCT	Conventional CT
1	1	1	2	2	2	1
2	1	1	2	2	3	3
3	2	1	2	2	2	2
4	1	1	2	2	3	2
5	2	1	2	2	3	2
6	1	1	2	2	3	1
7	2	1	2	2	3	2
8	2	1	2	1	3	2
9	2	1	2	2	3	2
10	2	1	2	2	3	1
11	2	1	2	1	3	1
12	1	1	2	2	3	2
13	1	1	2	2	4	1
14	1	1	2	2	3	2
15	1	1	1	1	2	2
16	4	1	2	2	3	2
17	1	1	2	2	3	1
18	1	1	1	1	2	1
19	1	1	2	2	3	2
20	3	1	2	2	3	1

CT – computed tomography, FDCT – flat panel detector CT

lowing the application of an EVD, like a contorted EVD tube.

This superiority of conventional CT might be caused by its higher soft-tissue resolution compared to FDCT – a finding also described in previous studies [23]. Still, the investigators did not report any excessive artefacts in the FDCT data, and the accuracy of FDCT regarding the position and intracranial course of an EVD is rather close to that of conventional CT. Only one case showed insufficient image quality for determining the EVD tip among the experienced radiologist rater group (see Fig. 8, conventional CT on the left and FDCT on the right side). The reason for the poor image quality was motion due to the patient's restlessness, since he suffered from severe intolerance to a laryngeal tube with additional temporal lack of sedation leading to movement artefacts and reduced image quality. In this case, conventional CT imaging might not have suffered in quality as much as FDCT imaging, since conventional CT tolerates patient movements better due to a shorter acquisition time. However, with improved coordination between radiologists and anaesthesiologists, this potential source of insufficient FDCT data can be avoided.

Among all FDCT examinations, only one image was concordantly rated to be of insufficient quality to deter-

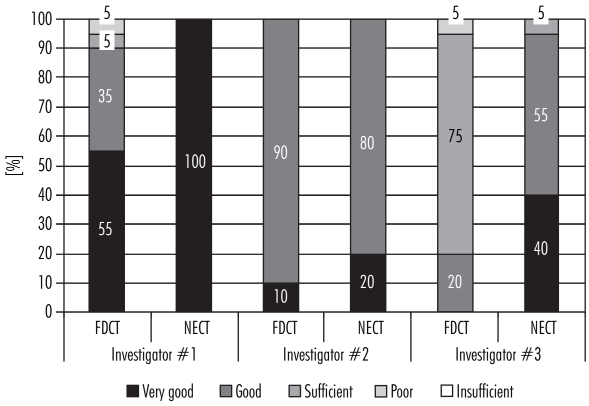

Fig. 7. Detectability of a contorted drainage tube

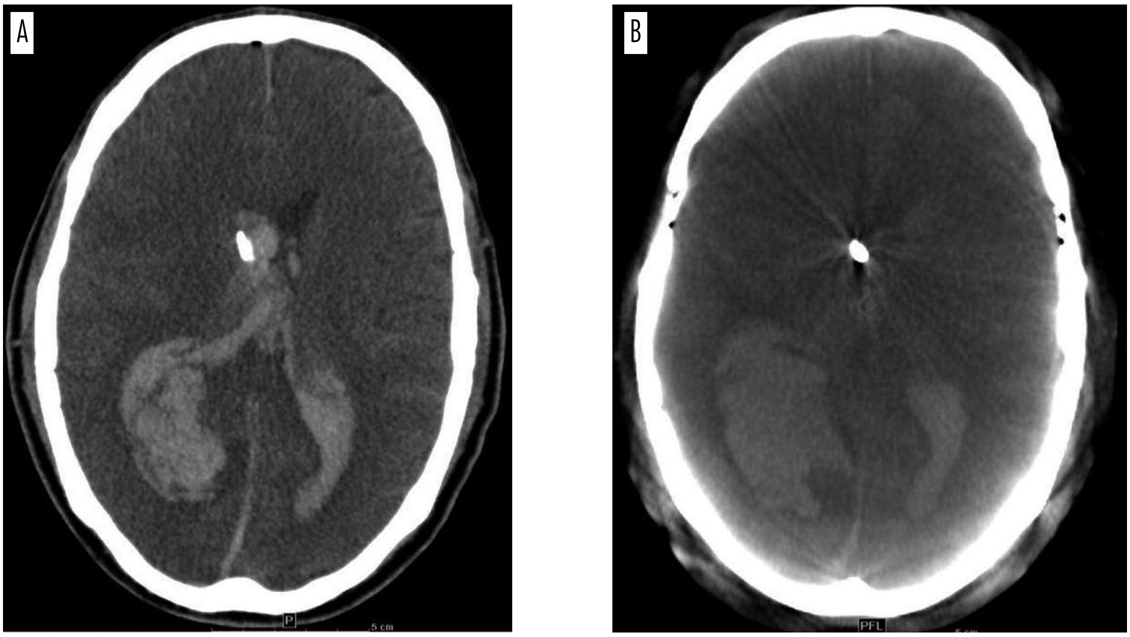

Fig. 8. The only case with FDCT-image quality rated 'insufficient' by the experienced radiologists for determining the EVD tip's position (FDCT on the right, B)

mine a correct EVD position by all three investigators (see Fig. 9, NECT on the left and FDCT on the right side). Patient #15 is one of the few patients with little intracranial blood but narrow inner ventricles due to over-drainage of cerebral fluid, which may result in difficult identification of intracranial anatomy of the ventricles. Manual adjustment of dose application may have been a solution here.

For the two experienced investigators, the FDCT data were of sufficient quality for determining a correct EVD position (average of 82.5%). Adding the novice investigator's findings, the results fall to 70%. This follows the general trend of investigator #3, who as a novice radiologist was rating the lowest amount of FDCT images with 'very good' or 'good' referring to the individual items.

Another important issue is the possibility to create multi-planar reconstructions from FDCT source images. This has not been included in our comparison study since the necessity of 3D data to assess the position of an EVD may be discussed in some radiological centres. Incremental 2D imaging might sometimes allow better differentiation of grey and white matter. Some radiologists therefore may prefer incremental 2D imaging when per-

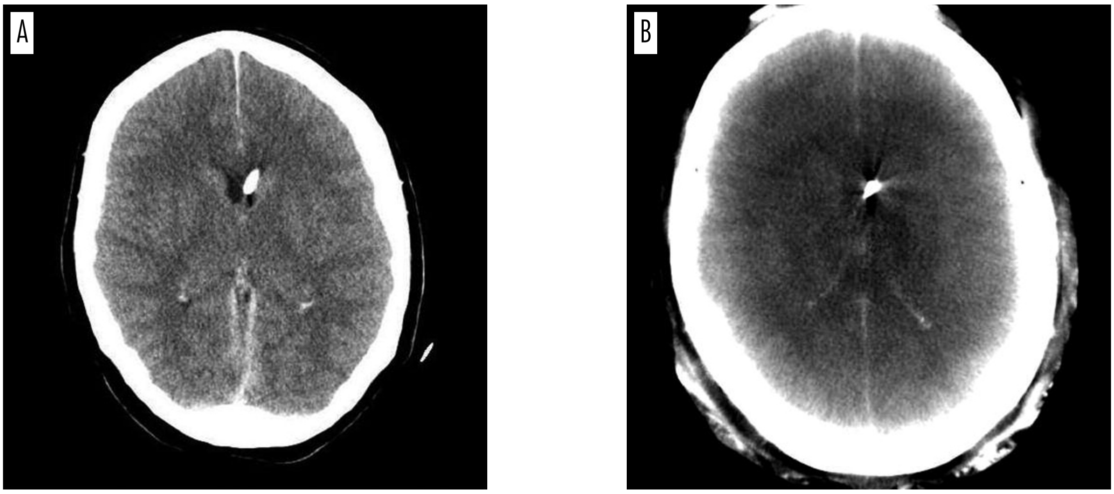

Fig. 9. The only FDCT-image considered being of 'insufficient' quality to determine a correct EVD's position by all three raters (FDCT on the right, B)

forming conventional CT, so the authors wanted to keep the level of comparison as high as possible.

We believe that by creating multi-planar reconstructions from FDCT data, the assessment of the EVD position would be facilitated even more. This could make it equal to conventional CT advantage in accuracy, especially for colleagues inexperienced in the assessment of tomographic head imaging.

It is also possible to create multi-planar reconstructions from conventional CT data, but this involves moving the patient to the CT scanner under possibly difficult circumstances.

Compared to conventional CT, FDCT has a lower CT dose index [16], which allows tomographic head imaging with reduced exposure to radiation for the patient. This is desirable especially in patients with SAH, since a lot of clinical monitoring with conventional CT might be necessary. As mentioned above, this also includes a certain loss of contrast, which might result in a lower distinguishability of tissue with only small differences in density and contrast – such as fresh haemorrhage and brain tissue adjacent to the EVD. It does not include the differentiation of normal brain tissue and the EVD, since these differ by a factor of about 10 in HU. This is also reflected by the good results referring to the detection of a contorted drainage tube.

Since the discussed problems of FDCT have been described by other users too, future developments of FDCT systems might assimilate the modality to the conventional CT method, resulting in improvement of contrast in tissue of small difference in density or less vulnerability to ground vibration. The issue of limited comparability is therefore of concern in this study, but may become more and more obsolete in the future.

The relatively small number of recruited patients can be considered as another weak point of this study. The value of FDCT to assess the EVD position might have been clearer in a study with a larger number of patients; however, in the author's opinion, the current results already show a major tendency towards a certain reliability of the FDCT in this issue.

This tendency is also reflected in the inter-rater reliability, which can be considered as 'moderate'. Choosing a group of investigators with more similar skills and a more equal level of experience might have raised the level of inter-rater reliability and may even have produced a clearer statement in this study. The chosen combination represents an actual manning at a radiological/neuroradiological institute, having a variety of skill and experience levels, and was therefore chosen by the authors. The applied scale has no matching correlate in the literature, but was cooperatively developed with colleagues of the neurosurgical ward and should represent the clinical relevant questions from daily work routine.

Conclusions

1. FDCT imaging can be of sufficient sensitivity for evaluating the correct position of an inserted EVD in a majority of cases. In comparison to conventional CT, the sensitivity of the demonstrated FDCT system is however still being suppressed by technical issues, rendering it inferior.
2. Still, the sensitivity shown in this study, combined with its comparatively low dose application, can justify FDCT imaging to be carried out after an intervention as primary assessment of an EVD position and status. It then facilitates the patients' management and renders transports and transfers to conventional CT scanners under possibly difficult conditions unnecessary. In the few cases where images produced by FDCT were rendered insufficient for the evaluation of an EVD position, an additional conventional CT has to be carried out afterwards.
3. Nonetheless, this study also shows that the evaluation of FDCT imaging is an experienced radiologist's task. Furthermore, FDCT does not replace conventional CT as follow-up examination for the evaluation of an SAH yet.

Acknowledgements

We thank Zwaka A., MD, for supporting us in the medical translation.

Disclosure

Authors report no conflict of interest.

References

1. Voldby B. Pathophysiology of subarachnoid haemorrhage. Experimental and clinical data. *Acta Neurochir Suppl* (*Wien*) 1988; 45: 1-6.
2. Hayashi M., Marukawa S., Fujii H., et al. Intracranial pressure in patients with diffuse cerebral arterial spasm following ruptured intracranial aneurysms. *Acta Neurochir* (*Wien*) 1978; 44: 81-95.
3. Grote E., Hassler W. The critical first minutes after subarachnoid hemorrhage. *Neurosurgery* 1988; 22: 654-661.
4. Gambardella G., De Blasi F., Caruso G., et al. Intracranial pressure, cerebral perfusion pressure, and SPECT in the manage-

ment of patients with SAH Hunt and Hess grades I-II. *Acta Neurochir Suppl* 1998; 71: 215-218.

5. Young J.S., Blow O., Turrentine F., et al. Is there an upper limit of intracranial pressure in patients with severe head injury if cerebral perfusion pressure is maintained? *Neurosurg Focus* 2003; 15: E2.
6. Hasan D., Vermeulen M., Wijdicks E.F., et al. Management problems in acute hydrocephalus after subarachnoid hemorrhage. *Stroke* 1989; 20: 747-753.
7. Suarez-Rivera O. Acute hydrocephalus after subarachnoid hemorrhage. *Surg Neurol* 1998; 49: 563-565.
8. Jaskólski D.J., Zawirski M., Jakubowski J. Various problems related to the occurrence of hydrocephalus after subarachnoid hemorrhage caused by ruptured cerebral aneurysm. *Neurol Neurochir Pol* 1992; 26: 208-215.
9. Kolluri V.R., Sengupta R.P. Symptomatic hydrocephalus following aneurysmal subarachnoid hemorrhage. *Surg Neurol* 1984; 21: 402-404.
10. van Gijn J., Hijdra A., Wijdicks E.F., et al. Acute hydrocephalus after aneurysmal subarachnoid hemorrhage. *J Neurosurg* 1985; 63: 355-362.
11. Gigante P., Hwang B.Y., Appelboom G., et al. External ventricular drainage following aneurysmal subarachnoid haemorrhage. *Br J Neurosurg* 2010; 24: 625-632.
12. Milhorat T.H. Acute hydrocephalus after aneurysmal subarachnoid hemorrhage. *Neurosurgery* 1987; 20: 15-20.
13. Toma A.K., Camp S., Watkins L.D., et al. External ventricular drain insertion accuracy: is there a need for change in practice? *Neurosurgery* 2009; 65: 1197-1200; discussion 1200-1201.
14. McKinney A.M., Palmer C.S., Truwit C.L. Detection of aneurysms by 64-section multidetector CT angiography in patients acutely suspected of having an intracranial aneurysm and comparison with digital subtraction and 3D rotational angiography. *AJNR Am J Neuroradiol* 2008; 29: 594-602.
15. Kalender W.A., Kyriakou Y. Flat-detector computed tomography (FD-CT). *Eur Radiol* 2007; 17: 2767-2779.
16. Psychogios M.N., Buhk J.H., Schramm P., et al. Feasibility of angiographic CT in peri-interventional diagnostic imaging: a comparative study with multidetector CT. *AJNR Am J Neuroradiol* 2010; 31: 1226-1231.
17. Heran N.S., Song J.K., Namba K., et al. The utility of DynaCT in neuroendovascular procedures. *AJNR Am J Neuroradiol* 2006; 27: 330-332.
18. Doelken M., Struffert T., Richter G., et al. Flat-panel detector volumetric CT for visualization of subarachnoid hemorrhage and ventricles: preliminary results compared to conventional CT. *Neuroradiology* 2008; 50: 517-523.
19. Struffert T., Doelken M., Adamek E., et al. Flat-detector computed tomography with intravenous contrast material application in experimental aneurysms: comparison with multislice CT and conventional angiography. *Acta Radiol* 2010; 51: 431-437.
20. Franklin B., Gasco J., Uribe T., et al. Diagnostic accuracy and inter-rater reliability of 64-multislice 3D-CTA compared to intraarterial DSA for intracranial aneurysms. *J Clin Neurosci* 2010; 17: 579-583.
21. Kyriakou Y., Struffert T., Dörfler A., et al. Grundlagen der Flachdetektor-CT (FD-CT). *Radiologe* 2009; 49: 811-819.
22. Landis J.R., Koch G.G. The measurement of observer agreement for categorical data. *Biometrics* 1977; 33: 159-174.
23. Irie K., Murayama Y., Saguchi T., et al. Dynact soft-tissue visualization using an angiographic C-arm system: initial clinical experience in the operating room. *Neurosurgery* 2008; 62 (3 Suppl 1): 266-272; discussion 272.