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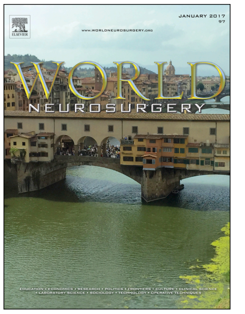

Preliminary results of Emergency CT guided Ventricular Drain Placement– Precision for the Most Difficult Cases

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Preliminary results of Emergency CT guided Ventricular Drain Placement– Precision for the Most Difficult Cases

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Abbreviations: cerebrospinal fluid (CSF), computed tomography dose index (CTDI), confidence interval (CI), dose-length product (DLP), External ventricular drainage (EVD)

Introduction

External ventricular drainage (EVD) catheter placement belongs to the most commonly performed neurosurgical procedures and allows to monitor intracranial pressure and to drain cerebrospinal fluid in case of elevated intracranial pressure. Accuracy of catheter placement and duration of insertion are two important factors, which determine the success of this potentially life-saving procedure in emergency cases. Positions of the EVD tip either in the ipsilateral frontal horn or in the third ventricle through the Foramen Monroe are considered as optimal[1]. Rates of up to 23 % of suboptimal placement have been reported[1-3]. Success rates strongly depend on ventricle width and presence of midline shift[1]. If more than one attempt for correct EVD placement is needed the risk of complications like intracerebral haemorrhage, injury of eloquent brain areas and iatrogenic infection increase significantly[4, 5]. Furthermore, the duration of EVD placement increases too, which might have an influence on outcome.

EVD placement either can be accomplished in the operating room or in emergency cases necessitating immediate action bedside in the emergency room or on the intensive care unit. Apart from classical landmark-based freehand insertion, several techniques have been described to improve accuracy and efficiency of EVD placement including stereotactic frame-based or frameless navigational systems, endoscopically assisted and ultrasound-guided techniques[6-9]. According to a recent meta-analysis stereotactic and ultrasound-guided catheter insertions significantly improve accuracy of placement compared to the freehand technique[9]. However, these techniques are elaborate and mostly restricted to application within the operating room. As an alternative to freehand landmark-based catheter insertion outside of the operating room CT-guided approaches have been described[10, 11]. The objective of the current work was to present an easy and reliable CT-guided approach for placement of bolt-kit EVD and to compare accuracy, expenditure of time, cumulative radiation dose as well as complication rates with conventional landmark-based insertions.

Materials and Methods

Patients

This is a single-center retrospective case-control study of patients who underwent emergency EVD placement in our department from January 2013 to December 2016. The institutional review board and the local ethics committee gave approval for the access and use of the data collective with the intention for retrospective clinical research. Only patients aged >18 years who underwent placement of the EVD immediately subsequent to the emergency CT scan (128-slice scanner; Somatom Definition Edge, Siemens Healthcare, Erlangen, Germany) bedded on the CT examination table were selected. Two patient groups were compared:

A) Patients who had the EVD implanted by freehand technique according to anatomical landmarks from January 2013 to May 2015. These patients served as the control group.

B) Patients who underwent CT-navigated bolt-kit EVD placement from May 2015 to December 2016.

Patients' charts, microbiology reports and hospital databases were reviewed. Exclusion criteria were incomplete data precluding outcome analysis and missing informed consent. Both groups were analysed for differences with respect to clinical characteristics including age and sex and the underlying clinical pathology necessitating EVD implantation.

EVD placement

Patients in both cohorts were operated by junior residents of the neuro intensive care unit who were usually in their 3rd to 5th year of training. All procedures were supervised by the senior author (WZG). In all patients a bolt-kit silver-bearing EVD catheter system (Silverline-Bolt-Kit-catheter®; Spiegelberg GmbH & Co. KG; Hamburg, Germany) was implanted. For skin preparation povidine-iodine (Betadine®, Mundipharma, Basel, Switzerland) and surgical drapes were used. A skin incision of approximately 5 mm was done at the site of the planned burr-hole trephination. The burr-hole was drilled with a manually operated twist drill. After the dura was perforated the bolt-kit system was screwed in the skull and the EVD was inserted. After successful placement the probe was fixed with the bolt screw.

Landmark-based freehand EVD placement

The Kocher`s point of the non-dominant side was chosen as entrance point. In cases of left-sided pathology, right-sided skull fractures or preceding right-sided craniotomy the left side was chosen. After burr-hole trephination the bolt was fixed with its trajectory aiming at the contralateral medial canthus in coronal plane and 1 cm anterior to the tragus in the anterior-posterior plane according to previous work by Raabe and co-workers[12]. Then, the EVD catheter was inserted. Insertion depth was typically no more than 5.5 to 6 cm. If no CSF could be extracted, a CT scan was performed to document catheter position. In case of incorrect placement, the catheter was removed. The surgeon undertook a second freehand placement with a different angulation of the bolt and re-inserted the catheter. This procedure was repeated until the catheter was successfully placed and CSF could be drained. In all cases, an immediate postoperative CT scan was performed, to rule out complications and to assess correct catheter placement.

CT bolt scan-guided EVD placement

The entrance point was chosen as described above. After drilling the burr hole the bolt was superficially screwed into the skull with the same trajectory as described above. An immediate CT bolt scan was performed before the insertion of the ventricular catheter to check its putative trajectory: to reduce the radiation dose, the CT scan only covered the rostral part of the skull including the bolt down to the beginning of the third ventricle. This typically leads to a reduction of the dose length product to 440 mGycm compared to a standard head CT scan (~690 mGycm). The CT data set was immediately reconstructed along the trajectory of the bolt. During this procedure, that usually lasted only 2-3 minutes, the patient stayed on the CT table with drapings in situ. If the axis of the bolt did not point towards the ipsilateral ventricle, the angulation of the bolt was adapted. Therefore, the surgeon removed the bolt and reinserted it, again, only superficially with the corrected angulation in order to counterbalance the deviation seen in the reconstructed CT. For instance, if the putative trajectory of the bolt pointed lateral to the ipsilateral frontal horn, the surgeon reangulated the bolt with the tip pointing more medial (Figure 1). A second CT scan was performed to check the new trajectory. This procedure was repeated until the correct bolt angulation was found. Only in this case, the bolt was screwed firmly into the skull and the catheter was inserted. A final postoperative CT scan was performed to assess correct catheter placement.

Determination of radiation exposure

The total number of CT scans (including the pre- and postoperative scans) as well as the cumulative radiation exposure were documented for each patient. The cumulative radiation dose was determined as the sum of the dose-length product of each CT scan:

$$DLP = CTDI_{VOL} * nT \quad (1)$$

with CTDI = computed tomography dose index and nT = product of the number of slices and slice thickness.

To calculate the effective dose (E) a conversion factor of 0.0021 for the head was applied according to Shrimpton et al.[13]:

$$E = DLP * 0.0021 \quad (2)$$

Assessment of ventricular configuration and of midline shift

The width of the lateral ventricles was determined on the preoperative CT scan. It was defined as the maximum diameter of the ipsilateral frontal horn measured perpendicular to the frontal horn`s axis. Midline shift was measured as the maximum deviation of the septum pellucidum from the midline.

Primary and secondary outcome measures

The primary endpoint was the contingency analysis of correct EVD placements in the ipsilateral frontal horn documented on the postoperative CT scan between the two groups. EVD placement was considered correct, when the catheter tip was placed within the *ipsilateral* frontal horn of the ventricle *or* passed through the foramen of Monro according to Wilson et al.[9] Placement was considered inaccurate, if the catheter was placed in the contralateral ventricle or outside the ventricular system.

Secondary endpoints were the between-groups differences of the number of EVD insertions during the entire procedure, the duration of the intervention, the number of CT scans performed, the mean dose length product as well as an analysis of combined infection parameters according to Fichtner et al.[14] and procedural haemorrhages.

Statistical analysis

Data were analysed with descriptive/parametric statistics using Prism software (GraphPad Prism 6, USA). The Shapiro-Wilk normality test was used to test for normal distribution of data sets. The Mann-Whitney-U test was applied to test for significant differences of metric variables between the two groups. Data are presented as mean ± standard deviation (SD) or mean ± 95% confidence interval (CI) if not otherwise indicated. The two-sided Fisher exact-test was applied for contingency analysis. A p-value < 0.05 was considered statistically significant.

Results

Patients' baseline clinical and radiological characteristics

34 patients fulfilled the inclusion criteria and were enrolled in the final analysis. 15 underwent CT-guided bolt-kit EVD implantation and 19 conventional landmark-based insertion. Baseline clinical and radiological characteristics of the two groups are shown in Table 1. Both groups were well matched for sex, age and underlying pathology necessitating EVD placement. In the CT-guided EVD implantation group the mean preoperative ventricular width was significantly smaller and the mean preoperative midline shift was significantly higher compared to the control group (Table 1).

Position of EVD tip

Contingency analysis of correct EVD tip position showed statistically significant differences between both groups. 15 out of 15 (100 %) CT-guided implanted EVDs were placed within the ipsilateral frontal horn compared to 12 out of 19 (63%) landmark based inserted EVDs (p=0.01, Fisher`s exact test). The odds for correct EVD placement was 18.6 (0.96 – 358.5 95% CI) for CT bolt scan-guidance. When taking into account all attempts including attempts of reinsertion after unsuccessful placement, contingency analysis showed also significant differences between both groups. 15 out of 22 (68%) CT-guided implanted EVDs were placed within the ipsilateral frontal horn compared to 12 out of 33 (36%) landmark based inserted EVDs (p=0.03, Fisher`s exact test).

CT bolt-scan-guidance allowed successful EVD placement with the tip in the frontal horn of the ipsilateral ventricle even in cases with slit ventricles or midline shift (Figure 2): EVD was placed correctly in 5 patients having slit ventricles with a frontal horn diameter of less than 3 mm and in 4 patients who had marked midline shift between 5 mm to 13.1 mm.

Secondary outcome parameter

Table 2 summarizes secondary outcome measures. Mean insertion time for definitive EVD catheter placement did not differ between groups (Table 2). Application of CT bolt-scan guidance reduced the number of unsuccessful EVD placement attempts. Up to 7 attempts (unsuccessful EVD placement without CSF drainage) were necessary for correct catheter placement in the freehand group. In 11 of 15 (73 %) patients the catheter was successfully placed at the first attempt in the CT-guided group compared to 9 of 19 (47 %) patients in the control group (p=0.17, Fisher`s exact test). It is noteworthy, that EVD misplacement within our series of patients undergoing CT bolt scan-guided EVD insertion mainly occurred in the first 3 patients while in 11 of the 12 consecutive patients (91.6%), EVD was correctly placed at the first attempt (Figure 3).

The overall number of CT scans performed during the entire procedure and the cumulative radiation dose was significantly higher in the CT-guided group compared to the freehand group (p=0.0001, Wilcoxon signed rank test). Within the freehand control group, one patient needed 8 CT scans after each attempt due to misplacement until the catheter was definitively placed correctly and fixed.

In both groups one patient was diagnosed a postoperative catheter infection (infection rate of 6.6 % in the CT-guided group and 5.2 % in the control group). A small postoperative subdural hematoma without compressive effect was diagnosed in the CT-guided group with no need for surgical evacuation.

Discussion

Our results demonstrate that CT bolt scan-guidance for EVD placement is accurate and successful even in very difficult cases of slit ventricles and marked midline shift deforming normal ventricular anatomy. In our series of 15 patients, all EVDs were correctly placed within the ipsilateral frontal horn whereas 37% of EVDs in the control group were misplaced. Application of the CT-guided approach did neither increase operation time nor postoperative complication rate. The increased success rate of correct catheter placement was at the expense of a higher radiation exposure of patients, higher costs and needed a short learning curve.

The rate of 37% misplaced EVD catheters in the control group is in line with previous studies. Two retrospective studies involving 346 and 98 patients undergoing bedside ventriculostomy with freehand insertion reported optimal catheter placement in 77% and 56.1% of patients[1, 2]. Recently, an analysis was conducted to re-examine the landmarks and rules to determine the entry point and trajectory with the best hit rate for freehand insertion. The authors found only a few entry points and trajectories, which were associated with a chance greater than 80% to hit the ipsilateral frontal horn and did not recommend the ipsilateral medial canthus as a landmark for latero-medial angulation[12].

Application of our CT-guided EVD placement approach led to 100% correctly placed catheters. The success rate of correct catheter placement after the first attempt was 78% when considering the whole cohort and rose up to 92.6% after the first three patients. Previous studies have already proposed numerous assisted methods to guide and improve accuracy of ventricular catheter placement. Application of stereotactic neuro-navigation for ventricular-peritoneal shunt implantation in the operating room reduced the malposition rate to 1.4% in a series of 70 patients[7]. Furthermore, Stieglitz et al. published a pilot study presenting a frameless neuronavigational tool for ventricular catheter placement and demonstrated successful placement in a series of 4 patients[8]. Wilson et al. compared ventricular catheter placement using freehand technique, ultrasonic guidance and stereotactic neuro-navigation in a retrospective cohort study of 249 patients. According to their results, application of ultrasound guidance and stereotactic neuro-navigation significantly improved accuracy of placement: whereas 55% catheters were correctly placed in the freehand cohort, 88% and 89% accuracy were achieved by applying ultrasound guidance and stereotactic neuro-navigation respectively[15]. The three cited studies analysed ventricular peritoneal shunt implantation in the operating room and, thus, results can hardly be compared to our series of patients undergoing EVD catheter placement in emergency situations. However, it is noteworthy, that the reported success rates of correctly placed catheters is comparable to our series of patients undergoing CT-guided EVD placement.

Considering assisted EVD placement, Mahan et al. published a series of 35 patients who underwent MRI-navigated EVD placement on the intensive care unit. Application of this approach led to correctly placed catheters within the ipsilateral frontal horn in 33 patients which corresponds to a success rate of 94.3%[6]. Average duration of the procedure was reported to be 2h 32 min[6] compared to 41 min in our series of patients. EVD placement under live fluoroscopic control has further been demonstrated in series of 5 patients by Fiorella and co-workers[10]. According to the authors` results, all catheters were correctly placed within the ipsilateral frontal horn requiring a single pass with no observed complications. However, implantation occurred in the neuroangiography suite and depended on a flat detector CT. Taken together, previous studies have already demonstrated that application of assisted techniques for ventricular catheter placement in general leads to a higher success rate of correct placement. However, the assisted techniques for ventricular catheter placement proposed by most of the previously presented studies increase procedural time and mostly depend on sophisticated neuronavigational equipment and thus, seem inappropriate in cases in which emergency EVD placement is required.

To facilitate and increase the accuracy of EVD placement, other devices exist such as the Thomale guide[16]. This device is placed on the skull after drilling a burrhole and is supposed to guarantee a right angle in the sagittal plane, whereas in the coronal plane an individual angle can be set with an angle adjustment according to the ventricular anatomy based on the CT scan[17]. Instead of adapting the bolt until it has the right angulation to point to the ipsilateral frontal horn, one single CT scan with the Thomale-guide attached to the skull could be sufficient to calculate and accordingly adjust the necessary angulation for correct placement. If this leads to a further increase of precision with a concomitant decrease in the number of needed CT scans, needs to be addressed in future studies.

Our study has some limitations. First, we compared the results of our CT-guided approach with patients undergoing anatomical landmark-based EVD implantation within the CT unit serving as the control cohort. The smaller ventricles and more pronounced midline shift in the CT-guided group could point to a selection bias. It is therefore important to emphasize, that the CT-guided approach was exclusively used after the first successful attempt in May 2015. The retrospective study design that included only patients within our CT unit was chosen, as it enabled an analysis of the exact number of misplaced drains and insertion attempts as well as the time of the procedure. These parameters were not systematically documented in our patients` charts undergoing freehand EVD implantation outside the CT unit or operating room and could not have been reliably analysed in these patients. It might be argued that our controls are already selected cases who were implanted under special conditions within the CT unit and, thus, do not constitute a generalizable control cohort for freehand implantation. However, the success rate of correctly placed catheters in our freehand group corresponds to that reported in the literature. Second, our results might not be generalizable to a broader population due to the small sample size and missing predetermined criteria of which patients are suitable for CT bolt scan-guided EVD implantation. Third, the proposed method depends on the use of a bolt-kit EVD system with a bolt type, which can be reliably detected with CT imaging.

Conclusions

CT bolt scan-guided EVD placement leads to accurate catheter placement even in the most difficult cases. Its safe, quick and easy application makes it an appropriate operative technique for patients with difficult ventricular anatomy.

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Figure Legends:

Figure 1: Bolt CT-target scanning for correct EVD placement. After slight fixation of the bolt a first CT scan was performed (A). Its angulation was further adapted to point to the ipsilateral frontal horn and right angulation was confirmed by a second CT scan before the catheter was inserted (B).

Figure 2: CT-guided EVD placement in a patient with slit ventricles (A-C) and another patient showing extreme midline shift (D-F): A preoperative CT scan (A,D) was routinely performed. After bolt fixation, a second CT was reconstructed along the axis of the bolt (B,E). When the bolt`s axis pointed towards the ipsilateral ventricle, the catheter was inserted. A postoperative CT scan (C,F) served to document correct EVD placement and rule out complications.

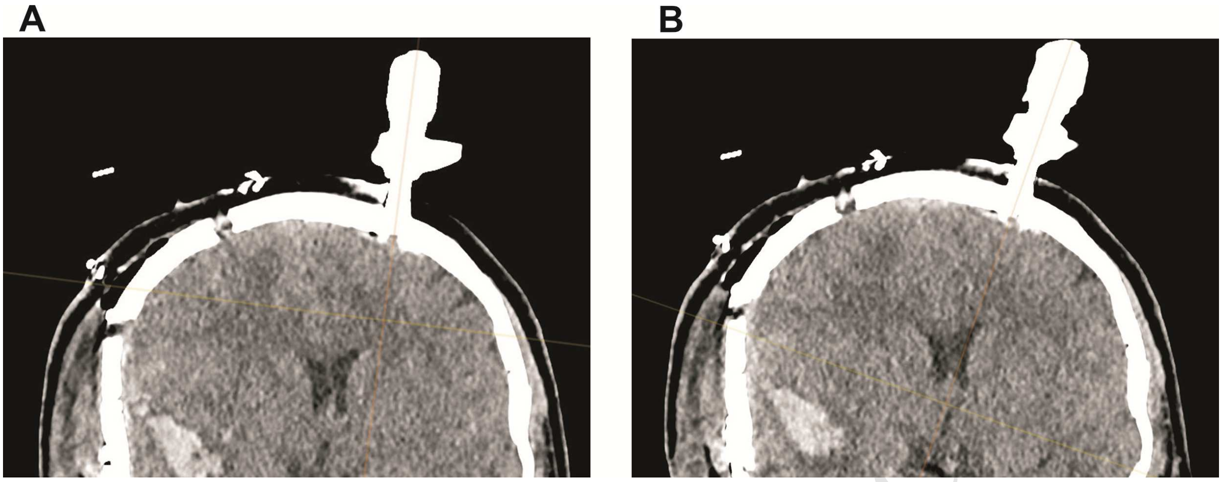
Figure 3: Learning curve of CT-guided EVD placements. Two to three attempts for correct final EVD placement in the ipsilateral frontal horn were necessary in the first three patients of our series. In the following 12 patients, only one attempt for correct EVD placement was necessary.

	Landmark-based insertion	CT-guided insertion	p-value
Sex			
- male	13 (68%)	8 (53%)	0.48˜
- female	6 (32 %)	7 (47 %)	
Age (years)	53 ± 18	46 ± 15	0.18§
Underlying pathology:			
- intracerebral haemorrhage	3 (16%)	3 (20%)	
- traumatic brain injury	11 (58%)	8 (53%)	
- subarachnoid hemorrhage	1 (5%)	2 (13%)	
- other	4 (21%)	2 (14%)	
Ventricular width (mm)	8.8 ± 6.1 (5.8 – 11.8)	5.2 ± 3.4 (3.2 – 7.1)	**0.04§**
Midline shift due to mass lesion (mm)	0.8 ±1.7 (0.01 – 1.7)	3.7 ± 4.0 (1.5 – 6.0)	**0.01§**

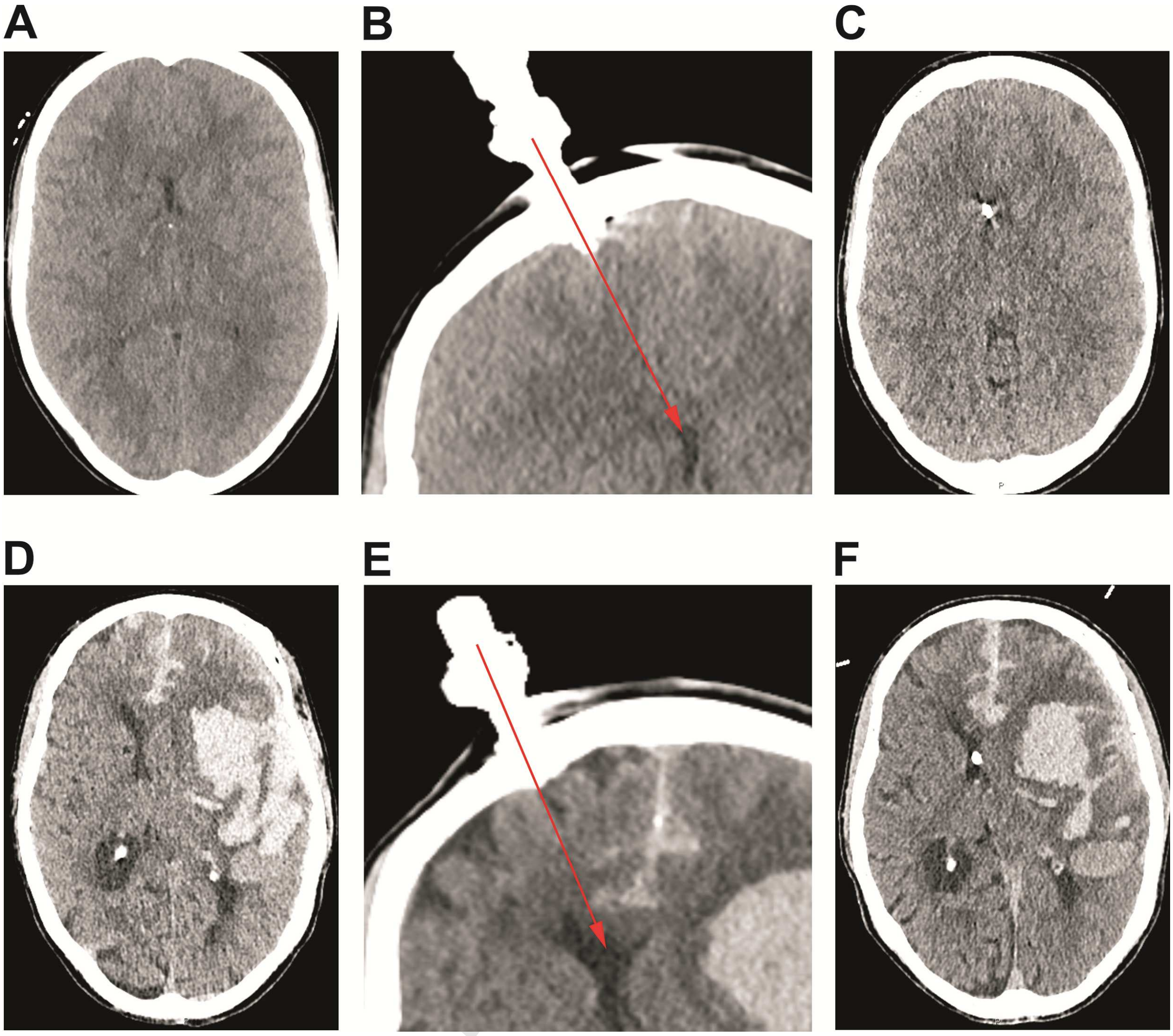
Table 1: Baseline clinical and radiological characteristics. Data are given as mean ± SD, and 95%-CI (in brackets), statistical testing based on Fisher exact test˜ and on Mann-Whitney-U test§

	Landmark-based insertion	**CT-guided insertion**	**p-value**
number of **attempts** for final catheter placement	1.7 ± 1.7 (range 1-7)	1.4 ± 0.74 (range 1-3)	0.98~
correct placement after 1st. attempt	9 of 19 (47%)	11 of 15 (73%)	0.17~
mean **insertion time (min)**	35:54 (± 16:42)	41:43 (± 16:01)	0.22§
number of **CT scans**	1.84 ± 2.0 (range 1-8)	3.6 ± 1.9 (range 2-8)	**0.0001§**
cumulative dose length product (mGycm) and effective dose (mSv)	738.4 ± 790.2 1.55 ± 1.66	1595 ± 766 3.34 ± 1.61	**<0.0001§**
Infection rate	1 of 19 (5.2%)	1 of 15 (6.6%)	1.0~
Procedural hemorrhage	0 of 19 (0%)	1 of 15 (6.6%)	0.44~

Table 2: Secondary outcome measures (attempts, correct placement after first insertion, insertion time, number of CT scans, dose length product, postoperative ventriculitis) between both groups *(statistical testing based on Fisher exact test~ and on Mann-Whitney-U test§).



A
B


A
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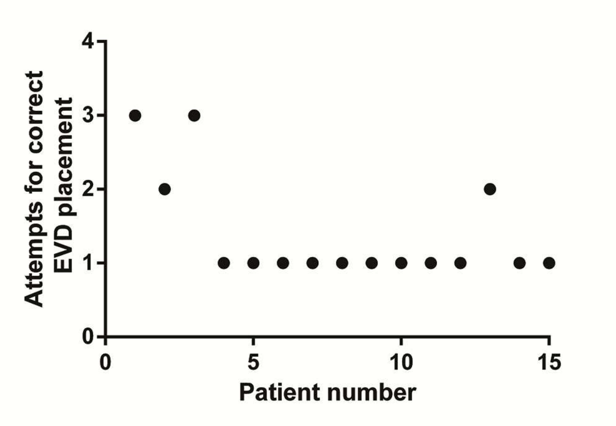
Attempts for correct EVD placement
Patient number
0
1
2
3
4
0
5
10
15

Highlights

- CT bolt scan-guided approach is based on a dose reduced CT scan after bolt fixation

- immediate image reconstruction along the axis of the bolt to evaluate the putative insertion axis

- CT-guided bolt-kit EVD catheter placement is feasible and accurate in the most difficult cases

Disclosure- Conflict of interest:

The authors did not receive any financial support for the following study. There are no conflicts of interest to be declared.