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ORIGINAL ARTICLE - CSF CIRCULATION

The Aalborg Bolt-Connected Drain (ABCD) study: a prospective comparison of tunnelled and bolt-connected external ventricular drains

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Abstract

Background Acutely increased intracranial pressure (ICP) is frequently managed by external ventricular drainage (EVD). This procedure is life-saving but marred by a high incidence of complications. It has recently been indicated that bolt-connected external ventricular drainage (BC-EVD) compared to the standard technique of tunnelled EVD (T-EVD) may result in less complications.

Aim To prospectively sample and compare two cohorts by consecutive allocation to either BC-EVD or T-EVD from the introduction of the BC-EVD technique in our department and 12 months onward.

Methods Patients undergoing ventriculostomy between the 1st of March 2017 and the 28th of February 2018 were considered for inclusion. The neurosurgeon on-call sovereignly set the indication and decided on EVD type (BC-EVD or T-EVD), consequently resulting in two cohorts as 3/7 senior neurosurgeons on call were open to the use of BC-EVD, while 4/7 were reluctant to use this technique. Data was continuously collected using patient records, including results of cerebrospinal fluid (CSF) culturing and available CT/MRI-scans. Recorded complications included CSF leakage, accidental discontinuation, placement-related intracranial haemorrhage, malfunction, migration, infection and revision.

Results Forty-nine EVDs (32 T-EVDs/17 BC-EVDs) were included; 19/32 (59.4%) T-EVDs and 3/17 (17.6%) BC-EVDs were found to have complications ($p = 0.007$). The relative risk of complications when using T-EVD was 3.4 times that of BC-EVD.

Conclusion Ventriculostomy by BC-EVD compared to T-EVD reduces incidence and risk of complications and should be the first choice in EVD placement. That said, T-EVD has a role in paediatric patients and for intraoperatively and occipitally placed EVDs.

Keywords Complications · Cranial bolt · Hydrocephalus · Neurosurgical technique · Subcutaneous drain tunnelling · Ventriculostomy

Abbreviations

BC-EVD	Bolt-connected external ventricular drain
EVD	External ventricular drain(age)
CSF	Cerebrospinal fluid
ICH	Intracerebral haemorrhage
ICP	Intracranial pressure
ICU	Intensive care unit
IVH	Intraventricular haemorrhage
SAH	Subarachnoid haemorrhage
SD	Standard deviation
T-EVD	Tunnelled external ventricular drain

Presentation at conferences Portions of this work were presented at the annual meeting (March 9, 2018) of the Danish Neurosurgical Society. Furthermore, the abstract has been chosen for oral presentation at EANS2018, Bruxelles, Belgium (October 24, 2018).

This article is part of the Topical Collection on *CSF Circulation*

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Introduction

Ventriculostomy/external ventricular drainage (EVD) is used for therapeutic drainage of cerebrospinal fluid (CSF) to an external drainage system. It also allows for reduction and monitoring of ICP, drainage of CSF for culturing, and for intrathecal administration of medication [4, 6, 8, 9, 12, 16, 17, 25, 26, 28, 34–36, 41, 42]. Indications for EVD include

acutely increased ICP caused by spontaneous intracranial haemorrhages (e.g. subarachnoid haemorrhage (SAH) or intracerebral or intraventricular haemorrhage (ICH/IVH)), hydrocephalus, intracranial tumours and head trauma [4, 6, 9, 15, 22, 23, 25, 29, 31, 34, 37, 42].

The first EVD procedure was described in 1744 [20, 24, 37]. Challenges included high rates of infections necessitating subsequent incorporation of antiseptic methods (using carbolic acid to prevent microorganisms from growing) [20, 37, 38], allowing observations on prolonged periods of placement, including excessive drainage [3]. In 1908, Tillmann formalised the EVD technique by describing placement through a precoronal burr hole at Kocher's point [37, 40]. The first closed system for EVD drainage was described in 1941 by Ingraham and Campbell [37]. Saunders added subcutaneous tunnelling, lowering the infection rate remarkably [33, 37], which was further substantiated by Friedmann and Vries [10, 37], and in 1985, Ghajar introduced a tripod for increasing placement accuracy [17, 29, 37]. Neuronavigation aided placement was further advanced by Hayhurst et al. (2009), using preoperative 3D brain CT, electromagnetic technology and the StealthStation Axiem navigation system to obtain high placement acccuracy [13].

Though the EVD technique has been optimised considerably since 1744, common complications necessitating frequent revisions still remain including the following: nosocomial infections and CSF leakage, inaccurate placement of the intracranial catheter, catheter migration, discontinuation of the drainage system and procedurally induced intracranial haemorrhages [1, 2, 5, 6, 9, 12, 17, 19, 41].

Among the EVD associated complications, infection has been given special attention. In the literature, infection rates range from 0 to 45% [1, 4–6, 11, 12, 15–18, 21, 23, 25, 27, 28, 31, 32, 34–37, 39, 41, 43], although the infection rate depends on how ventriculostomy-related infection is defined [11, 18, 28]. Thus, in a literature review by Lozier et al. (2002), the infection rate (defined as the cumulative rate of positive CSF cultures) was 8.08% per EVD [28]. Factors predisposing to infection was also thoroughly investigated; among substantiated predisposing factors were as follows: IVH, ICH and SAH, ICP > 20 mmHg, CSF leakage around the intracranial catheter, concurrent infections and breach of the closed drainage system for CSF sampling [4, 12, 15, 16, 18, 22, 25, 27, 28, 31, 36, 41].

In order to reduce the high ventriculostomy-related infection rate, antibiotic-impregnated EVD catheters were introduced in 2003 [42], while silver-impregnated EVDs were described in 2010 [7]. Cui et al. (2015) have recently reviewed the literature on this emerging field, concluding that whether EVDs were impregnated by silver or by antibiotics, there was an advantage over plain EVDs [5].

EVD is traditionally placed on the right side by freehand technique aiming for the foramen Monro of the ipsilateral lateral ventricle at a depth of 5.5–6.5 cm [1, 10, 19, 37]. The extra cranial portion of the catheter is then tunnelled 5 to 6 cm subcutaneously away from the burr hole, so-called tunnelled EVD (T-EVD) [8, 35]. The procedure is typically done in an operating theatre or in emergencies in the intensive care unit (ICU) [1, 4, 6, 9, 26]. Some use neuronavigation for EVD placement, theoretically increasing placement accuracy [1, 13, 26, 37]. The EVD procedure is generally performed by neurosurgical residents, specialised neurosurgeons and neurointensivists, depending on the traditions of a given centre [6, 9, 29, 37].

The T-EVD technique has retrospectively been associated with a complication rate of up to 40.0% [19]. An alternate option, the bolt-connected EVD (BC-EVD), was described in a Danish retrospective study by Bergdal et al. (2013), who demonstrated increased placement accuracy and fewer reoperations [1]. A subsequent retrospective Danish study by Jensen et al. (2016) on complications due to T-EVDs compared to BC-EVDs found that BC-EVD had a complication rate of 6.5% compared to the afore mentioned 40.0% observed in T-EVDs, resulting in a risk ratio of 4.9 times the risk of complications when using T-EVD instead of BC-EVD [19].

Thus, in 2017, we were the only remaining neurosurgical department in Denmark not using BC-EVD, although the formerly mentioned two Danish studies had clearly indicated that this procedure was superior to the T-EVD technique [1, 19]. Accordingly, the BC-EVD technique was introduced to our department, although only 3/7 senior colleagues were positive towards using BC-EVD, while the remaining 4/7 senior colleagues were reluctant towards BC-EVD and preferred to use T-EVD. Consequently, the use of either BC-EVD or T-EVD was made optional, and completely dependent on the senior neurosurgeon (7/7) in charge when the decision to place an EVD was taken. We, the authors, had no influence on which EVD technique was used, but expected that 3/7 of forthcoming patients generated would be treated with BC-EVD, and 4/7 be treated with T-EVD.

Hence, the aim of this study was to prospectively sample and compare two cohorts by their consecutive allocation to either BC-EVD (adopted by 3/7 senior neurosurgeons) or T-EVD (preferred by 4/7 senior neurosurgeons) from the time of the introduction of the BC-EVD technique in our department and 12 months onward.

Methods

The study included all patients in need of an EVD at the neurosurgical unit of Aalborg University Hospital from the 1st of March 2017 and until the 28th of February 2018.

The local (regional) committee on health research ethics evaluated the project before initiation and did not consider it to be an interventional trial, as the BC-EVD technique was used at the other Danish neurosurgical departments [1, 19],

and because no patient would be allocated to a different EVD technique other than the one preferred and selected by the senior neurosurgeon in charge. Thus, only a permission from the Danish Data Protection Agency (Datatilsynet) was required and accordingly obtained (Journal No. 2017-52). Furthermore, ethical considerations included the exclusion of children, due to their developing craniums not tolerating bolts [19]. Routine postsurgical cerebral CT was not a part of the study protocol, as the decision to scan the patient was only made when an on-call doctor found that it was indicated, thus ensuring that the patients did not undergo any additional risks due to their participation in the study.

EVDs were excluded from the study if patient age < 15 years, if the patients were transferred to other hospitals during ongoing EVD treatment or if the EVD had to be placed through a craniotomy or occipitally.

The neurosurgeon on-call sovereignly set the indication and decided on EVD type (BC-EVD or T-EVD), consequently resulting in two prospectively gathered cohorts as 3/7 senior neurosurgeons on-call were open to the use of BC-EVD, while 4/7 were reluctant to use this technique.

Surgical technique

The EVD was inserted intracranially either via freehand technique [12] or with neuronavigational guidance (StealthStation® AxiEM™ Electromagnetic Navigation) [13], depending on the preference of the senior neurosurgeon in charge.

T-EVD

Kocher's point is identified at the non-dominant side. A local anaesthetic (lidocaine 10%/adrenaline 0.5‰) is applied, followed by a 4.0-cm skin incision. A manual twist drill (diameter 17 mm) is used to make a burr hole. The dura is cauterised cruciately using a bipolar, then incised using a dural scalpel. The meningeal edges are cauterised, followed by insertion of a "CODMAN® BACTISEAL® EVD catheter set, 82-1745" through the burr hole. Placement accepted after CSF was observed. The extracranial or distal portion of the catheter is then tunnelled subcutaneously 5 to 6 cm away from the burr hole and fastened to the skin by vicryl sutures.

BC-EVD

At Kocher's point, a local anaesthetic (lidocaine 10%/adrenaline 0.5‰) is applied, followed by a 0.5-cm incision. A twist drill (diameter 2.71 mm) is used to make a burr hole, through which a perforator is used to sharply perforate the dura. A "Silverline® Ventricular Catheter with Cranial Bolt, 8F, EVD30.014.02, Spiegelberg" is inserted through the burr hole. Placement accepted after CSF was observed. The bolt is then screwed into the burr hole.

Evaluations and definitions

Data on patient age, sex, EVD indication, EVD type (BC-EVD/T-EVD), operating surgeon (specialist, resident, other, and if supervised, whether the supervisor was in the operating theatre during the procedure), technique (freehand or navigationally guided) and number of penetrations were collected using a preformed questionnaire which was filled out during surgery.

The duration of EVD treatment and associated complications was subsequently collected using patient records, including available results of CSF culturing and CT/MRI. Recorded complications included CSF leakage, accidental discontinuation, placement-related intracranial haemorrhage, malfunction, migration, infection and revision.

Infection was defined as positive microscopy or culturing of CSF in a patient presenting clinical symptoms of a central nervous system infection, e.g. meningeal irritation, altered consciousness or mental status. CSF was not routinely tested [15, 25, 28, 36].

Positioning accuracy was evaluated as some of our neurosurgeons routinely used neuronavigation, while others routinely use freehand technique when placing EVDs. Accuracy of positioning was subdivided as optimal, suboptimal or failure. An assessment of available postsurgical CT/MRI was performed by the two authors. Optimal placement was defined as correct placement in the foramen Monro of the ipsilateral lateral ventricle. Suboptimal placement was defined as placement in the contralateral ventricle, third ventricle, in the posterior horn of the ipsilateral ventricle or if the tip of the drain was wrong-angled (posteriorly or anteriorly). Failure was defined as tip placement in brain parenchyma. Failure was considered a complication, whereas suboptimal placement was not counted as a complication. As mentioned, postoperative imaging was not routinely done, as it was not part of the study protocol. This means that only some EVDs could be assessed with regard to accuracy of positioning and was position accuracy was accordingly not included in the total calculation of complications.

Statistical methods

SPSS (version 25) was used for statistical analysis that both included descriptive statistics for the general study population and for subdivision by EVD type. For calculation of statistical significance, Fisher's exact test was applied. Significance was defined as two-sided $p < 0.05$.

Results

Forty-six patients were treated with a total of 62 EVDs. Thirteen EVDs were excluded (7 EVDs were placed via

craniotomies, 2 EVDs were placed occipitally, 1 EVD was placed via an old burr hole and 3 EVDs were excluded, as the patients were transferred to other hospitals). The remaining 49 EVDs were included in the analysis, and their baseline demographics are shown in Table 1. Note that the EVD treatment length was similar for the T-EVD and the BC-EVD groups.

Of the 49 included EVDs, 32 were T-EVDs and 17 were BC-EVDs (Table 1).

Nineteen out of 32 (59.4%) T-EVDs were found to have complications, whereas complications were only encountered in 3 out of 17 (17.6%) BC-EVDs ($p = 0.007$) (Table 2). Based on these numbers, calculating the risk ratio results in T-EVDs having 3.4 times the risk of complications compared to BC-EVD. The joint incidence rate per EVD treatment day for complications, infections and revisions was 6.0%, 0.8% and 2.2% respectively (Table 2). In comparison, the specific values for T-EVD versus BC-EVD for complications were 8.0% versus 2.4%, for infection 1.3% versus 0.0% and for revisions 3.4% versus 0.0%, respectively, and thus consistently higher for the T-EVD (Table 2).

Thus, 22 EVDs had a total of 36 complications (Table 3). One T-EVD had 3 complications, 12 T-EVDs had 2 complications and 9 EVDs (6 T-EVDs and 3 BC-EVDs) had 1 complication each, making the total number of observations (including drains with 0 complications) when each complication is counted separately a total of 63 (Table 3). Of the 63 observations, 46 were T-EVDs and 17 were BC-EVD. Of the 63 T-EVD observations, only 13 (28.3%) had no complications, whereas 14 BC-EVDs (82.4%) of the 17 BC-EVD observations had no complications ($p < 0.000$). The 33 (71.7%) T-EVD complications included 6 (13.0%) cases of CSF leakage, 2 (4.3%) counts of accidental discontinuation, 3 (6.5%) cases of intracranial haemorrhages, 10 (21.7%) cases of malfunction, 1 (2.2%) case of migration, 3 (6.5%) cases of infection and 8 (17.4%) cases of revision. In comparison, 3 (17.6%) BC-EVD complications included 1 (5.9%) case of accidental discontinuation, 1 (5.9%) case of intracranial haemorrhage and 1 (5.9%) case of malfunction (Table 3). It is notable that no cases of CSF leakage, migration, infection or revisions were encountered when using BC-EVD, though no statistical significance was achieved for the subspecified complication types due to the low number of included EVDs (Table 3).

Positioning accuracy could be evaluated for 23 EVDs (17 T-EVDs and 6 BC-EVDs) that had cerebral imaging (either MRI or CT) following EVD-placement. The 17 T-EVDs were placed by freehand technique and the 6 BC-EVDs were placed using neuronavigation. Placement was optimal for 7 T-EVDs and not optimal for 10 T-EVDs, whereas 5 BC-EVDs were optimally placed and 1 BC-EVD was not optimally placed ($p = 0.095$) (Table 4).

Table 1 Baseline demographics for all EVDs, and when subdivided into T-EVD or BC-EVD

	EVDs	T-EVD	BC-EVD
Number of included EVDs, *n* (%)	49 (100.0)	32 (65.3)	17 (34.7)
Mean age, years (SD)	52.6 (17.5)	50.3 (19.0)	57.1 (13.6)
Treatment duration, days (SD)	7.4 (5.9)	7.4 (5.7)	7.5 (6.4)
Gender, *n* (%)			
Female	15 (30.6)	11 (34.4)	4 (23.5)
Male	34 (69.4)	21 (65.6)	13 (76.5)
Indications, *n* (%)			
Spontaneous intracranial haemorrhage	24 (49.0)	15 (46.9)	9 (52.9)
Neurotrauma	11 (22.4)	10 (31.3)	1 (5.9)
Tumour	5 (10.2)	5 (15.6)	0 (0.0)
Hydrocephalus	3 (6.1)	2 (6.3)	1 (5.9)
Other	6 (12.2)	0 (0.0)	6 (35.3)

Discussion

In the current study, it was prospectively found that BC-EVD has fewer complications than T-EVD, as the use of T-EVD had 3.4 times the risk of complications compared to BC-EVD. This was found despite the population size of this study being small both due to the size of our neurosurgical unit and the limited 1-year period over which the study was conducted.

Thus, 49 EVDs were included over a period of 1 year. A larger sample size would strengthen the results, though in comparison Bergdal et al. (2013) included 154 EVDs retrospectively over approximately 2 years [1]. This means they included approximately 77 EVDs annually, which is only slightly higher than the 49 EVDs included in the current study, even though the referral area of Rigshospitalet, Copenhagen, is about three times that of Aalborg University Hospital.

It was decided beforehand to exclude children under the age of 15 years old, and EVDs placed through a craniotomy and/or occipitally. The use of a cranial bolt is not recommended in

Table 2 Incidence rates for complications, infection and revision per EVD treatment day

	T-EVD	BC-EVD	*p* value
Complications, *n* (%)			0.007
No	13 (40.6)	14 (82.4)	
Yes	19 (59.4)	3 (17.6)	
Total	32 (100.0)	17 (100.0)	
Incidence rate per day (SD)			Total
Complications	8.0% (6.1)	2.4% (2.0)	6.0% (4.8)
Infection	1.3% (1.0)	0.0% (0.0)	0.8% (0.7)
Revision	3.4% (2.6)	0.0% (0.0)	2.2% (1.7)

Table 3 The total number of observations when each complication is counted separately and subdivided in relation to EVD type

	T-EVD	BC-EVD	Total
Observations, *n*	46	17	63
Complications, *n*	33	3	36
Complication types (%)			*p* value
None	13 (28.3)	14 (82.4)	0.000
CSF leakage	6 (13.0)	0 (0.0)	0.178
Accidental discontinuation	2 (4.3)	1 (5.9)	1.000
Intracranial haemorrhage	3 (6.5)	1 (5.9)	1.000
Malfunction	10 (21.7)	1 (5.9)	0.262
Migration	1 (2.2)	0 (0.0)	1.000
Infection	3 (6.5)	0 (0.0)	0.557
Revision	8 (17.4)	0 (0.0)	0.095
Total	46 (100.0)	17 (100.0)	

children under 15 years of age due to their thinner and weaker skull [19]. Similarly, EVDs placed through a craniotomy will normally exclude the option of a proper burr hole in which the BC-EVD can be screwed, while occipitally placed BC-EVDs would hinder supine bed rest. Hence, these select groups were not suitable for free allocation to our prospective BC-EVD cohort. Consequently, it is recognised that T-EVD will keep playing a role in EVD treatment.

Our seven on-call specialised neurosurgeons were offered an unrestricted choice between BC-EVD and T-EVD. We expected and benefited from the probability that they would choose the EVD type and technique they were familiar with. Thus, two cohorts were achieved for comparison, as three of our colleagues were familiar with BC-EVDs from previous employments and were expected to choose this approach after its introduction. The remaining four on-call neurosurgeons were expected to continue with T-EVD. By not forcing BC-EVD into our unit, it was hoped to let the results speak for themselves and nudge our clinicians towards the same EVD technique currently used in the rest of Denmark. An important point, as going through the literature of EVD reveals that, although, extensive research has been done over the years [37], the neurosurgical community seems challenged when it comes to complying with the findings [4]. A challenge, we experienced as well, but in this instance to the benefit of the current study. We expect our patients to comply with our treatment plans. But since compliance is such an important part of medicine, why do we not comply with the literature? Proper neurosurgical research has been done over the years, but still, the literature shows major discrepancies when it comes to implementing these findings in daily clinical practice [4]. So why do we cut corners? It seems, we lack general guidelines to this common procedure that is often performed by neurosurgical residents, who are presumably also the least experienced [33] as well as the procedure being performed by neurointensivists in some centres [6]. General guidelines would provide easy access to scientifically based recommendations. This standardisation process could offer the least experienced a list of recommended options, precluding discussions on personal preferences that may even be outdated. It could also play part in the cost-effectiveness for the neurosurgical centres, as lowering complications and reinsertions would probably lower cost. Equally important, the question on increasing EVD positioning accuracy, which has already had addressed several times in the literature [1, 11, 14, 29, 37], versus the theoretical increase in procedural time could be addressed; maybe even with options for individualisation when considering the pathophysiological mechanism—are the ventricles compressed or enlarged? Or whether it even matters when it seems that positioning accuracy may be increased in any case [1, 11, 29].

Table 4 The results of placement accuracy subdivided with regard to EVD type. The T-EVDs which placement could be assessed were placed using freehand technique, whereas the BC-EVDs were placed using neuronavigation

	T-EVD	BC-EVD	*p* value
Optimal placement, *n* (%)			0.095
No	7 (41.2)	1 (16.7)	
Yes	10 (58.8)	5 (83.3)	

As anticipated, no cases of CSF leakage developed using the BC-EVD, whereas 6 cases of CSF leakage were recorded for T-EVD. The bolt is screwed into the burr hole, ensuring complete closure over the dural puncture, thus preventing CSF leakage, as has been suggested in the literature [19, 36], and likewise is clearly indicated in the current study, although we did not reach statistical significance due to the small sample size.

The bolt is also suggested to decrease the number of migrations and of unintended discontinuations, as the bolt is screwed into the cranium, whereas, T-EVDs are relatively loosely fastened via tunnelling and sutures. Thus, it was expected that the BC-EVD cohort had fewer, if any, discontinuations than the T-EVDs cohort. As expected, no cases of migration occurred in the BC-EVD cohort, whereas a single case of migration was seen in the T-EVD cohort. In the current study, 2 T-EVDs were discontinued. But initially in the study, we likewise encountered a single case of unintended discontinuation in the BC-EVD group which we attribute to learning curve errors. In the actual case, no revision was needed, as the accidental continuation occurred while drainage was closed off and the patient did not require further CSF reduction.

As mentioned, the T-EVDs are fastened to the skin by sutures, whereas the distal catheter of the BC-EVD is kept in place by the bolt and, thus, hangs freely. Suturing the catheter to the skin necessitates tightening the sutures, which may compress the lumen of the catheter, causing a stricture to develop. This in turn may cause malfunction due to mechanical

compression [19]. In the current study, 10 cases of malfunction developed in the T-EVD cohort, whereas only a single case of malfunction occurred in the BC-EVD cohort.

The above mentioned would indicate that placement of T-EVDs results in more complications than placement of BC-EVDs, and that the amount of revisions in the T-EVD cohort would consequently be higher as well. It was observed that 8 T-EVDs needed revising, while no BC-EVD had to be revised.

In the current study, there was a low incidence of CSF culture positive infection in both the T-EVD group (6.5%) and the BC-EVD group (0%) which is lower than reported in a systematic review showing a pooled cumulative infection rate of 8.08% per EVD [28]. Notably, both EVD types in the current study were impregnated; BC-EVDs were silver impregnated and T-EVDs were impregnated with antibiotics. A meta-analysis by Cui et al. (2015) has accordingly concluded impregnated catheters are more effective than plain EVDs in preventing catheter-related infections, although, the data did not allow further conclusions on the superiority of one coating or the other [5].

In the current study, positioning accuracy could be evaluated for 23 EVDs. Seventeen T-EVDs were placed using the freehand technique and 6 BC-EVDs were placed using neuronavigation, requiring a preoperative STEALT-CT sequence. Though non-significantly, it was found that placement was optimal using the freehand technique for 10/17 (58.8%) T-EVD placements, whereas 5/6 (83.3%) neuronavigated BC-EVDs were optimally placed. Statistical significance could not be obtained, likely due to the small sample size, as a post-operative CT/MRI was not part of the research protocol. Still, theoretically, neuronavigation should increase accuracy of placement, especially for the person performing the procedure, whether resident, specialised neurosurgeon or neurointensivist. What is often argued against neuronavigation is the additional time consumption [30, 37] and even the Ghajar guiding tripod [11, 29], which improves positioning accuracy, is opposed due to extension of the procedural time [29, 37]. Neuronavigation, however, could not only provide some additional security for the least experienced, but it could also be argued as necessary and indispensable in, e.g. neurotrauma patients with compressed ventricular system, implicating that the indication for EVD (compressed ventricles or large ventricles) must be considered when planning whether to use the freehand or neuronavigational placement technique.

Conclusion

In accordance with two retrospective Danish studies [1, 19], we prospectively found that BC-EVD is superior to T-EVD, as the relative risk of complications when using T-EVD was 3.4 times that of BC-EVD. No revisions were seen in the BC-EVD group, whereas the T-EVD group had 8 cases of revisions. Accordingly, we recommend that BC-EVD should be the first choice for ventriculostomy, although T-EVD will continue playing a role in paediatric patients and when EVDs are placed through craniotomies and/or occipitally.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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