VERSITA

Cent. Eur. J. Med. • 8(2) • 2013 • 250-256
DOI: 10.2478/s11536-012-0115-8

Central European Journal of **Medicine**

Infections of external ventricular drainages

Research Article

Tadej Strojnik[1,2], Jasmina Golc*[2], Jasna Zakelšek[2]

1 Department of Neurosurgery, University Clinical Centre Maribor, Ljubljanska 5, 2000 Maribor, Slovenia

2 University of Maribor, Faculty of Medicine, Slomškov trg 15, 2000 Maribor, Slovenia

Received 11 May 2012; Accepted 14 November 2012

Abstract: Aim. The most common complication of the external ventricular drainage (EVD) is an infection, which is linked to different risk factors. We tried to investigate possible links between different risk factors and incidences of an infection of the EVD. Materials and Methods. We used a retrospective method and examined records of 176 patients. These patients were admitted to the University clinical centre Maribor between January 2004–December 2005 and January 2009–December 2010 and had an EVD inserted. Results. Our research had shown a high overall occurrence of infection, namely 23.3 %. We found a significantly higher incidence of infection in patients with a subarachnoid haemorrhage as an etiology. The likelihood of an infection increased with each catheter replacement and with EVDs inserted for more than 7 days. The incidence of infection in the group of patients with an impregnated catheter was significantly lower. The protective role of impregnated catheters is larger in terms of local effect and smaller in broader effect in CSF space. Conclusions. An easy retrograde route for microorganisms to enter ventricular space should be prevented with appropriate wound care and by replacing EVDs only in cases of mechanical dysfunction or extraction.

Keywords: *External ventricular drain (EVD) • Infections of EVD • Impregnated catheter • Duration of an EVD • EVD replacement.*

1. Introduction

External ventricular drainages (EVDs) are silastic catheters commonly used to divert a pathologic excess of cerebrospinal fluid (CSF) from the ventricles of the brain to the exterior in patients with different etiologies, including traumatic brain injury, subarachnoidal hemorrhage, communicating hydrocephalus, spontaneous intracerebral hemorrhage and cerebral ischemia [1,2].

Although EVDs are known for their efficiency, their benefits can be diminished by complications associated with their use. The most common and serious complication is infection. It occurs in 0 % –45 % of patients [2, 3], while in majority of cases the likelihood of infections ranges between 5 and 15 % [1,2,4].

Considering previous studies there is a great range of various definitions of an EVD related infections, which had been discovered in the study of Lozier et al. [5].

Ragel et al. defined a drain-related infection as positive cultures of either a sample of CSF or of samples of the tip of a catheter with at least one clinical manifestation of the infection [6].

The most frequently found microorganisms are Gram-positive bacteria, nevertheless we found certain contradictions in the literature [5,7,8].

In order to reduce the rate of infection, the use of antibiotic-impregnated catheters had recently increased. Using special procedures the silicon matrix of these catheters is impregnated with different antibiotics [9].

We did the research at the Department of Neurosurgery at the University Clinical Centre Maribor. During the period in question the rate of EVD-associated infections was high. We looked for potential risk factors, in order to find ways to reduce the rate of drain-related infections.

* *E-mail: stella.the.one@gmail.com*

2. Material and Methods

Using a retrospective method we examined 176 patients that were admitted to the University Clinical Centre Maribor at the Department of Neurosurgery, Department for Intensive Care or Department for Perioperative Care. Data were collected retrospectively, from patients admitted to the hospital between January – December 2005 and January – December 2010, using patient's medical charts and documentation. During this period researched patients had an EVD inserted as part of their therapy.

We used the following parameters for our research: age of the patient, sex, comorbidity, GCS at presentation, skull fracture, etiology for EVD insertion (traumatic brain injury, subarachnoidal hemorrhage, communicating hydrocephalus and spontaneous intracerebral hemorrhage and cerebral ischemia), duration of the drainage, number of changes of the catheter, use of antibiotic-impregnated catheters.

We divided patients into two groups according to the duration of an EVD – first one with an EVD inserted for less than 7 days and second one for 7 days or more. If an EVD replacement was applied several times, the duration of individual instances was summed up.

At the Center for Microbiology, Health Insurance Institute Maribor, we used a computer program (MBL, Infonet Kranj, Slovenia) in order to gain data for microbiological samples of CSF or from the tip of the catheter.

2.1. Definition of an EVD-associated infection

We defined an EVD-associated infection as every positive culture (a sample of CSF and/or a sample from the tip of the catheter) with systemic manifestations of the infection (high C-reactive protein (CRP) and elevated body temperature).

2.2. An EVD and ICP sensor insertion

An EVD catheter was inserted in sterile conditions. Scalp hair around the incision was removed using hair clipping. The operating field was cleaned and disinfected with povidone-iodine solution and sterile dressing was applied. A skin incision was made 10 cm above the nasion and 3-4 cm laterally from the midline. A small burr hole was made. The dura was punctuated and a standard non-impregnated/ impregnated EVD catheter (Thomy F.E., MicroVention Terumo, Elkton, MD, United States/ Codman Bactiseal Clear EVD Catheter Set, Workingham, United Kingdom) was inserted through the brain tissue into the frontal horn of the right lateral ventricle. The distal catheter was tunnelled subcutaneously, fixed on the skin surface and connected to the external drainage system (Codman, Johnson & Johnson, Workingham, United Kingdom). Sensor for measuring ICP (ICP Codman monitor, Workingham, United Kingdom) was inserted through the same burr hole, fixed on the skin surface and connected with the device for ICP monitoring. The wound was closed using atraumatic sutures and covered with sterile adhesive plaster.

2.3. Microbiologic testing

CSF samples were taken every two days using an aseptic method following the protocol of the University Clinical Centre Maribor and were placed in a sterile test tube: CSF samples were then sent to the microbiologic laboratory (Centre for Microbiology, at the Health Insurance Institute Maribor). One part of a CSF sample was tested for cultures, while the remaining part was tested with a qualitative method and left in a cookmeat bouillon for 10 days. Upon removal of the EVD and ICP sensor a tip was placed in the test tube with the cookmeat bouillon and sent to the microbiologic laboratory (Centre for Microbiology at the Health Insurance Institute Maribor) where it was incubated for 10 days. After a period of 10 days the samples were tested for their sterility; if bacteria are found, the identification system VITEK (Biomereiux, Marcy l'Etoile, France) is used (Center for Microbiology, the Health Insurance Institute Maribor).

3. Statistical methods

We performed a biostatistical analysis using SPSS Statistics version 19 (IBM Corporation, Chicago IL). Data was compared with the Pearson's Chi-square test. With multiple logistic regressions we investigated the influence of different risk factors on the risk of EVD-related infections. We calculated the corresponding p-value for each test. For the purposes of our study, a p-value of < 0.05 was considered to be significant.

4. Results

During the period of 48 months, 176 patients had an EVD inserted while they were hospitalised. Of the 176 patients, 41 experienced an EVD-related infection, what amounted to 23.3% of patients.

Table 1. Demographic data/variables and their effect on EVD-associated infections.

Demographic data		All patients (n = 176)	Non-infected (n = 135)	Infected (n = 41)	p
Sex	Male (%)	110 (62.5)	81 (60.0)	29 (70.7)	0.27
	Female (%)	66 (37.5)	54 (40.0)	12 (29.3)	
Age	Median age	56.5	56.0	57.0	
	Age above 60 yrs (%)	69 (39.2)	56 (41.5)	13 (31.7)	0.28

Legend: yrs = years

4.1. Demographic data

Demographic data and their effect on EVD-associated infections are summarized in Table 1. No significant correlation with infection was found in this group of observed data.

4.2. Etiology

Etiologies that lead to the insertion of an EVD are shown in Table 2. Among patients with inserted EVD the most frequent etiology found was traumatic haematoma with 44.3% of cases, followed by SAH (28.4%) and spontaneous ICH (14.8%). Other etiologies were less common in our group of patients.

Table 2. Etiologies that lead to the insertion of an EVD.

Etiology	All patients (n = 176)	Non-infected (n = 135)	Infected (n = 41)	p
Traumatic hematoma (%)	78 (44.3)	64 (47.4)	14 (34.1)	0,154
SAH (%)	50 (28.4)	33 (24.4)	17 (41.5)	0,047
Spontaneous ICH + ICV (%)	26 (14.8)	20 (14.8)	6 (14.6)	1,000
Communicating hydrocephalus (%)	25 (14.2)	16 (11.9)	9 (22.0)	0.126
Intraventricular hemorrhage (%)	21 (11.9)	14 (10.4)	7 (17.1)	0.274
TU (%)	20 (11.4)	15 (11.1)	5 (12.2)	0.785

Legend: SAH - subarachnoidal hemorrhage, ICH - intracranial hematoma, ICV - cerebrovascular insult, TU – tumor.

A significant correlation between etiology and infection rate was found only for subarachnoid haemorrhage (p = 0.047). In the group of infected patients with subarachnoid haemorrhage the median age was 60.0 years (non-infected 51.0 years), the median duration of inserted EVDs was 15.0 days (non-infected 8.0 days), the median number of changed drainages was 1.0 (non-infected 0.0) and the percentage of impregnated catheters used was 14.3 % (non-infected 85.7%).

4.3. Duration of inserted EVDs

In Table 3 we presented the data concerning the duration of CSF drainage in the group with no replacements of the catheter and its influence on the incidence of EVD-associated infections. The incidence of infections was higher in the group of patients with an EVD inserted for 7 or more days. Median duration of drainage in group of infected patients was 13.0 days (non-infected 7.0 days).

Table 3. Duration of the drainage in the group with 0 changes of the catheter.

Duration of the drainage in the group with 0 changes	All (n = 138)	Non-infected (n = 116)	Infected (n = 22)	p
Duration < 7 days	74 (53.6)	76 (57.8)	7 (31.8)	0.035
Duration > 7 days	64 (46.4)	49 (42.4)	15 (68.2)	
Median	8.0	7.0	13.0	

4.4. The number of EVDs replacements

The number of catheter replacements and their effect on infection rate is shown in Table 4. We compared the incidence of EVD-related infections between the group of patients that had undergone no catheter replacements and the group of patients with at least one catheter replacement. The incidence of EVD-related infections was higher in the group with at least one change of the catheter. The difference between compared groups was significant (p < 0.001).

Table 4. Number of changes of EVD.

Number of changes of EVD	All (n = 176)	Non-infected (n = 135)	Infected (n = 41)	p
0 (%)	138 (78.4)	116 (85.9)	22 (53.7)	< 0,001
> 1 (%)	38 (21.5)	19 (14.0)	19 (46.4)	

4.5. Antibiotic-impregnated catheters

We observed the effects of an antibiotic impregnation on the incidence of infections.

The median duration of the drainage in the group with an impregnated catheter was 8.0 days, the same as in the group with non-impregnated catheter.

When comparing patients with impregnated catheters (n=100=56.8%) with those who had standard non-impregnated catheters (n=76=43.2%) we found

that the incidence of infections was lower in the group with impregnated catheters (39.0%) in comparison to the group with non-impregnated catheters (61.0%). The difference was statistically significant (p = 0.011).

Table 5 shows the difference between positive cultures of a sample of CSF and positive cultures of a sample from the tip of the catheter in the group with impregnated catheters and the group with non-impregnated catheters.

Table 5. Impregnated catheters and positive cultures.

	Non-impregnated catheters n=76	Impregnated catheters n=100	p
Infection confirmed* (%)	25 (32.9)	16 (16.0)	0.011
Positive culture- the tip of the catheter (%)	13 (17.1)	4 (4.0)	0.004
Positive culture-CSF (%)	19 (25.0)	14 (14.0)	0.08

**positive culture (a sample of CSF and/ or a sample from the tip of the catheter) with systemic manifestations of the infection (high C-reactive protein and elevated body temperature)*

4.6. Microbiological Factors

The most common causative organisms, found either in the CSF samples or in samples from the tip of the catheter, can be found in the Table 6. We isolated 83 microorganisms from the samples. The majority of EVD-related infections were caused by coagulase-negative staphylococcus, accounting for 43.4% of cases, followed by Acinetobacter sp. (13.2%).

Table 6. Most common causative organisms (%)

Causative organisms	Number (%)
Coagulasis-negative Staphylococcus	36 (43.4)
Acinetobacter sp.	11 (13.2)
Candida albicans	6 (7.2)
Propionibacterium acnes	4 (4.8)
Pseudomonas sp.	4 (4.8)
Diphteroid	4 (4.8)
Enterobacter sp.	3 (3.6)

4.7. Logistic regression

With logistic regression we demonstrated the influence of selected variables on infection rate. We analysed age (over 60 years), the duration of the drainage (7 or more days), the number of catheter replacements (>1), impregnation of the catheter and the source of infection outside the CNS (sepsis, urinary tract infection or pneumonia). Statistically significant influence was found when the duration of an EVD exceeded 7 days (p = 0.004), when the number of catheters replacement was high (p = 0.011) and if impregnated catheters were used (p = 0.049), whereas the age above 60 years (p = 0.107) and infections outside the CNS (p = 0.843) were not confirmed as prognostic factors for occurrence of EVD-associated infections. The most significant factors are presented in Table 7.

Table 7. Most significant risk factors

Significant risk factors	p
Duration >7 days	0.004
Number of changes >1	0.011
Impregnated catheters	0.049

5. Discussion

In the majority of studies the incidence of EVD-associated infections ranges from 0% to 22% [2,10,11]. Differences in methods and wide range of definitions of infections lead to differences in infection rates and are thus the main reason for a difficult interpretation of reported results. Our study presented a high incidence of infection, 23.3%.

Considering the age (over 60 years) and sex of the patients, our study showed no significant correlation. This result is in concordance with the findings of other studies, which disputed their effect on higher infection rate [12-14].

The examination of the etiology of EVD replacements showed that most patients were suffering from traumatic haematoma, followed by subarachnoidal hemorrhage. We found a significant correlation between etiology and infection rate in our study in patients with SAH. In one of the study it was demonstrated that hemorrhagic CSF – as a consequence of SAH or intraventricular hemorrhage (IVH) – occurred four times more frequently with a group of infected patients compared to the non-infected group [15]. Additionally the potential effect of SAH and IVH on the infection rate was mentioned in some of the later studies [7,16-19]. Within our study the correlation between SAH and higher incidence of infections proved to be significant. Hemorrhagic blood may be considered an excellent media for increased bacterial growth, what could explain a higher incidence of EVD-related infections with SAH. It is important to emphasise that infected patients with SAH also had more other co-existing potential risk factors that non-infected, which may had an effect on the result.

The duration of an EVD as a potential risk factor is still being discussed [8]. We established a significant correlation between the longer duration of an EVD and the higher infection rate. In majority of studies similar

results were confirmed [2, 20-23]. One of the past studies – Lyke et al. – showed that the mean duration of an EVD in the group of non-infected patients was 5.07 days, while the duration of an EVD replacement was significantly longer in the group of infected patients, namely 8.45 days (p = 0.007) [2]. The study by Mayhall et al. established a higher incidence of ventriculitis when EVDs were inserted for more than 5 days [11]. One of the studies, performed by Scheithauer et al., denied any correlation between the duration of the drainage and the incidence of infection [19]. The correlation between the duration of EVD replacements and the incidence of an EVD-associated infection was well established in our research. We examined the group of patients that had no EVD replacements, what excluded the potential effect of contamination during the catheter replacement. It can be assumed that a longer contact between the catheter and the closed CSF space contributes to a higher incidence of infections due to its ability to create a potential media for bacterial growth. The results concluded that the duration of the EVD presents itself as an independent risk factor for infections. The possibility of an infection drastically increases when the drainage is inserted for 7 days or more. Thus we can conclude that the 7th day is a crucial point, beyond which infections are much more likely to occur.

We found that more frequent EVD replacements are associated with a higher infection rate. In concordance with our findings a study by Wong et al. showed a higher risk for infections with multiple changes of EVDs [24]. According to some previously performed studies the most effective way is to change the EVD every five days after the procedure, as stated in the research by Mayhall et al. [20]. With results obtained in our research we oppose those recommendations since it makes for an easy retrograde route for microorganisms to enter CSF and ventricular space.

Antibiotic-impregnated catheters are considered to be an important factor in terms of its potential ability to decrease chances of an infection. Certain studies confirm a strong effect of impregnation on decreasing the incidence of EVD-associated infections [25,26]. One study established that antibiotic-impregnated catheters are associated with twice less frequent colonization in comparison to non-impregnated catheters. Moreover, positive cultures of CSF samples were seven times less likely with the use of impregnated catheters compared with non-impregnated catheters [15]. On the other hand, there are some studies which could not prove the effect of impregnated catheters on reducing the infection rate compared with non-impregnated catheters [27]. In our study we demonstrated significant differences in how efficient impregnated and standard, non-impregnated catheters are. We discovered a difference in terms of protective role of antibiotics released from impregnated catheters. Impregnation significantly decreased the likelihood of finding positive samples from the tip of the catheter. Thus we can conclude that impregnation has a strong local protective role. In discordance, the frequency of positive cultures in CSF samples was lower in the group with impregnated catheters, although it was not significant. Considering these results, the protective role of impregnated catheters is larger in terms of local effect and smaller in broader effect in CSF space.

Microorganisms, obtained from samples of CSF and/or samples from the tip of the catheter, are different in various studies. Lyke et al. discovered the causative organisms of EVD infections were predominantly Gram-negative bacteria (83%) [2], while the majority of studies emphasized the presence of Gram-positive bacteria [7]. Similarly, most frequently microorganisms found in our study were Gram-positive bacteria, with the dominance of coagulase-negative staphylococci, mostly derived from normal patient's skin flora. An EVD insertion may cause an infection which may further lead to an inoculation of skin microorganisms into the previously sterile closed intracranial compartment. The retrograde colonization risks result from the continuous externalization of the CSF space (for CSF sampling) but on the other hand may be a consequence of a potential route of entry for cutaneous organisms which was created while an EVD was being inserted [5,7].

6. Conclusion

We found that the longer insertion time and several changes of EVD increase the infection rate and confirmed that impregnated catheters reduce the occurrence of an infection. A significant correlation between etiology and infection rate was found in patients with SAH. As expected these risk factors are the most evident causes of infections related to EVD insertion. According to predominance of Gram-positive bacteria, the emphasise should be put on avoiding the possible contamination from patient's skin flora, with appropriate wound care and by replacing EVDs only in cases of mechanical dysfunction or extraction of the catheter and not daily as a routine, since it makes for an easy retrograde route for microorganisms to enter CSF and ventricular space. When using impregnated catheters we recommend avoiding the replacing of a EVDs too often and recommend leaving the catheter at the primary position, while with the use of standard non-impregnated catheters changing of the catheter more frequently is considered reasonable.

References

[1] Ratilal O.B., Costa J., Sampaio C., Antibiotic prophylaxis for surgical introduction of intracranial ventricular shunts, The Cochrane Collaboration. Published by JohnWiley & Sons, 2009: Ratilal B.O., Costa J., Sampaio C., Antibiotic prophylaxis for surgical introduction of intracranial ventricular shunts. Cochrane Database of Systematic Reviews 2006, Issue 3. Art. No.: CD005365: p. 2-3

[2] Lyke K.E., Obasanjo O.O., Williams M.A., et al., Ventriculitis complicationg use of intraventricular catheters in adult neurosurgical patients. Clin. Infect. Dis., 2001, 33(12), 2028-2033

[3] Popp W., Muller O., Schoch B., et al. Infektionsraten bei externen Ventrikeldrainagen. Hyg. Med. 2004, 29 (Suppl 1)

[4] Claus B.C., Shunt Infection. In: H. Richard Winn (Eds.), Youmans Neurological Surgery, 5th Ed., Vol. 3, Philadelphia: Saunders, 2004, 3419–3425

[5] Lozier A.P., Sciacca R.R., Romagnoli M.F., et al., Ventriculostomy-related infections: a critical review of the literature, Neurosurgery, 2002, 51(1), 170-81; discussion: 181-182

[6] Ragel B.T., M.D., Browd S.R., M.D., Ph. D., and Schmidt R.H., M.D., Ph.D. Surgical shunt infection: significant reduction when using intraventricular and systemic antibiotic agents, J. Neurosurg., 2006, 105, 242-247

[7] Cheng H L.O., MBBS, Spelman D., FRACP, FRCPA, Bailey M., PhD, Cooper J., MD, FRACP, FJFICM, Rosenfeld J.V., MS, FRACS, and Brecknell J.E., PhD, FRCS. External ventricular drain infections are independent of drain duration: an argument against elective revision, J. Neurosurg., 2007, 106, 378–383

[8] Prabhu V.C., Kaufman H.H., Voelker J.L., Aronoff S.C., Niewiadomska- Bugaj M., Mascaro S., et al. Prophylactic antibiotics with intracranial pressure monitors and external ventricular drains : a review of the evidence, Surg. Neurol.,1999, 52, 226-36, discussion 236-237

[9] Megerian J.T., Comparative Infection Rates for the Codman BACTISEAL TM External Ventricular Drainage (EVD) System, Clinical Research Review. Codman & Shurtleff

[10] Alleyne C.H. Jr., Hassan M., Zabramski J.M., The efficacy and cost of prophylactic and perioprocedural antibiotics in patients with external ventricular drains, Neurosurgery, 2000, 47, 1124–27, discussion 1127–1129

[11] Guyot L.L., Dowling C., Diaz F.G., Michael D.B., Cerebral monitoring devices: analyzes of complications, Acta Neurochir., 1998, Supp. 71, 47-49

[12] Choksey M.S., Malik I.A., Zero tolerance to shunt infections: can it be achieved? J. Neurol. Neurosurg. Psychiatry, 2004, 75, 87–91

[13] Borgbjerg B.M., Gjerris F., Albeck M.J., et al., Risk of infection after cerebrospinal fluid shunt: an analysis of 884 first-time shunts. Acta Neurochir., 1995, 136, 1–7

[14] Davis S.E., Levy M.L., McComb J.G., et al., Does age or other factors influence the incidence of ventriculoperitoneal shunt infections? Pediatr. Neurosurg., 1999, 30, 253–257

[15] Stenager E., Gerner-Smidt P., Kock-Jensen C., Ventriculostomy related infections – an epidemiological study. Acta Neurochir. (Wien), 1986, 83, 20–23

[16] Korinek A.M., Reina M., Boch A.L., et al., Prevention of external ventricular drain-related ventriculitis, Acta Neurochir. (Wien), 2005, 147, 39–46

[17] Pfisterer W., Muehlbauer M., Czech T., et al., Early diagnosis of external ventricular drainage infection: results of a prospective study, J.Neurol. Neurosurg. Psychiatry, 2003, 74, 929–932

[18] Ehtisham A., Taylor S., Bayless L., et al., Placement of external ventricular drains and intracranial pressure monitors by neurointensivists, Neurocrit.Care, 2009, 10, 241–247

[19] Scheithauer S, Buergel U, Ryang YM, Haase G, Schiefer J, Koch S, et al. Prospective surveillance of drain-associated meningitis/ ventriculitis in a neurosurgery and a neurologic intensive care unit. J Neurol Neurosurg Psychiatry 2009; 80: 1381–1385

[20] Mayhall C.G., Archer N.H., Lamb V.A., Spadora A.C., Baggett J.W., Ward J.D., et al, Ventriculostomy-related infections : A prospective epidemiologic study, N. Engl. J. Med., 1984, 310, 553-559

[21] Williams T.A., PhD, Gavin L.D., PhD, Geoeffrey J.D., MBBS, FCICM., Bright R., RN, Van Heerden V. P., PhD, Decrease in proven ventriculitis by reducing the frequency of cerebrospinal fluid sampling from extraventricular drains, J.Neurosurg., 2011

[22] Khanna R.K., Rosenblum M.L., Rock J.P., Malik G.M., Prolonged external ventricular drainage with percutaneous long-tunnel ventriculostomies, J. Neurosurg., 1995, 83, 791–794

[23] Luerssen T.G., Chesnut R.M., Van Berkum-Clark M., Marshall L.F., Klauber M.R., Blunt B.A., et al., Post-traumatic cerebrospinal fluid infections in the Traumatic Coma Data Bank: the influence of the type and management of ICP monitors, in Avezaat C.J.J., Van Eijndhoven J.H.M., Mass A.I.R., Tans J.T.J. (Eds): Intracranial Pressure VIII: Proceedings of the 8th International Symposium on Intracranial Pressure, Berlin, Springer-Verlag, 1993, pp 42–4519

[24] Wong G.C.K., Poon W.S., Wai S., Yu L.M., Lyon D., Lam J.M.K., Failure of regular external drain exchange to reduce cerebrospinal fluid infection: result of a randomised controlled trial, J. Neurosurg. Psychiatry, 2002, 73, 759-761

[25] Piatt J.H. Jr., Carlson C.V., A search for determinants of cerebrospinal fluid shunt survival: retrospective analysis of a 14-year institutional experience, Pediatr. Neurosurg., 1993, 19, 233–242

[26] Zabramski M.J. , M.D., Whiting D., M.D., Darouiche R.O., M.D., Horner T.G., M.D., Olson J., M.D., Robertson C., M.D., and Hamilton A.J., M.D., Efficacy of antimicrobial-impregnated external ventricular drain catheters: a prospective, randomized, controlled trial, J. Neurosurg., 2003, 98, 725–730

[27] Soleman J, Marbacher S., Fandino J., Fathi A.R., Is the use of antibiotic-impregnated external ventricular drainage beneficial in the management of iatrogenic ventriculitis?, Acta Neurochir. (Wien), 2012, 154(1), 161-4, discussion 164