Child's Nervous System (2019) 35:1147–1153
https://doi.org/10.1007/s00381-019-04163-7

ORIGINAL ARTICLE

The value of cerebrospinal fluid lactate levels in diagnosing CSF infections in pediatric neurosurgical patients

Jonathan Roth[1] · Jehuda Soleman[1] · Danil A. Kozyrev[1] · John N. Jabang[1] · Maya Stein[1] · Galia Grisaru-Soen[2] · Haggai Benvenisti[1] · Efraim Sadot[3] · Shirley Friedman[3] · Itay Ayalon[3] · Ilana Goldiner[4] · Moshe Stark[4] · Eyal Hassoun[4] · Shlomi Constantini[1]

Received: 20 March 2019 / Accepted: 16 April 2019 / Published online: 8 May 2019

Abstract

Purpose Diagnosis of cerebrospinal fluid (CSF) infections in patients following neurosurgical procedures can be challenging. CSF lactate (LCSF) has been shown to assist in differentiating bacterial from non-bacterial meningitis in non-neurosurgical patients. The use of lactate in diagnosing CSF-related infections following neurosurgical procedures has been described in adults. The goal of this study was to describe the role of LCSF levels in diagnosing CSF-related infections among neurosurgical children.

Methods We retrospectively collected data for all pediatric patients treated at a large tertiary pediatric neurosurgical department, for whom CSF samples were collected over a 2-year period. Lactate levels were correlated with other CSF parameters, surgical parameters, presence of CSF infection, and source of CSF sample (lumbar, ventricular, or pseudomeningocele).

Results A total of 215 CSF samples from 162 patients were analyzed. We found a correlation between lactate levels and other CSF parameters. Lactate levels displayed an inconsistent correlation with infection depending on sample origin. Irrespective of the CSF source, lactate levels could not sufficiently discriminate between those with or without infection. Lactate levels were correlated with recent surgery, and, in some of the subgroups, to the extent of blood in CSF.

Conclusions LCSF levels are influenced by many factors, including the source of sample, recent surgery, and the presence of subarachnoid or ventricular blood secondary to surgery. The added value of LCSF for diagnosing CSF infections in children with a history of neurosurgical procedures is unclear and may be influenced by the extent of blood in the CSF.

Keywords Neurosurgery · Infection · Meningitis · Aseptic · Lactate

Introduction

Bacterial meningitis and ventriculitis are a potentially life-threatening condition, both in the spontaneous setting, and also following invasive procedures to the CNS. Differentiation between bacterial and non-bacterial (aseptic) meningitis is based on various CSF variables; the gold standard for this is the culture. However, in an acute setting (until final cultures are available), CSF pleocytosis with high white cell count and a high percentage of polymorphonuclear (PMN), coupled with hypoglycorrhachiya, elevated protein levels, and a positive gram stain, are all suggestive of a bacterial infection. In addition, since cultures may be negative in a partially treated patient, polymerase chain reaction (PCR) may identify genetic imprinting of bacteria, which would confirm the diagnosis of a bacterial infection. This diagnostic cascade has been used for both adults and children in the diagnosis of spontaneous meningitis.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00381-019-04163-7) contains supplementary material, which is available to authorized users.

✉ Jonathan Roth
jonaroth@gmail.com

[1] Department of Pediatric Neurosurgery, Dana Children's Hospital, Tel Aviv Medical Center, Tel Aviv University, 6 Weizman Street, Tel Aviv-Yafo, Israel

[2] Pediatric Infectious Disease Unit, Dana Children's Hospital, Tel Aviv Medical Center, Tel Aviv University, Tel Aviv-Yafo, Israel

[3] Pediatric Intensive Care Unit, Dana Children's Hospital, Tel Aviv Medical Center, Tel Aviv University, Tel Aviv-Yafo, Israel

[4] Clinical Biochemistry and Pharmacology laboratory, Tel Aviv Medical Center, Tel Aviv, Tel Aviv-Yafo, Israel

As opposed to spontaneous cases, patients who underwent recent neurosurgical procedures may have altered CSF parameters. These altered values are either "as expected" following surgery or may represent an inflammatory response to surgical-related factors, such as blood, bone dust, exposure to air, and others. Following surgery, CSF is usually bloody and has an increased white cell count, increased protein, decreased glucose, etc. In addition, these patients are often perioperatively treated with antibiotics, and sometimes prophylactically, for several days, as well as with steroids, which may alter the immune response to inflammation and infection. Symptoms such as fever, headache, vomiting, and altered consciousness are not uncommon following neurosurgical procedures and may not necessarily be related to infection. Thus, differentiating between a bacterial infection and any other condition, based on clinical and CSF analysis, may be difficult [17].

It has been shown that lactate levels in the CSF (LCSF) correlate with bacterial infections in the spontaneous setting, both in adults and children [18]. Currently, literature regarding postoperative LCSF as a marker for bacterial infection is sparse, and limited mostly to the adult population [10, 14–16, 21, 28].

The goal of this study is to evaluate the role of LCSF in children admitted to a neurosurgical service, some of whom had recent surgery, as a marker for bacterial infections. We also tried to correlate LCSF to surgical factors and CSF parameters.

Methods

Following institutional review board approval, we retrospectively collected data from all neurosurgical children who underwent CSF analysis. Beginning November 2015, we routinely measured lactate levels in all CSF samples sent from pediatric neurosurgical patients. We also maintained an ongoing registry of these patients. The study period was November 2015 to December 2017. Inclusion criteria were age < 20 years old, patient presenting to the neurosurgical care with a need for CSF analysis, available CSF lactate levels, available clinical history, and course during hospitalization. Patients with missing data (LCSF or clinical course during hospitalization) were excluded from analysis.

Diagnosis of infections

Definition of CNS infection is broad and dependent on multiple factors, both clinical and laboratory. In 2017, the IDSA (Infectious Diseases Society of America) published relevant guidelines for the various types of infections [22]. Regardless of the infection type, a positive culture is considered the gold standard for diagnosis.

Our antibiotic regimes are strict: vancomycin + ceftriaxone perioperatively (24 h) for all neurosurgical patients undergoing an intradural procedure (unless a known allergy). Cefuroxime (second-generation cephalosporine) is given thereafter, for as long as drains are in place (external ventricular drains, externalized shunts, lumbar drains, and subcutaneous drains).

Once a patient is suspected of being infected, based on clinical condition and/or traditional CSF findings (excluding LCSF), broad spectrum antibiotics are administered until verification of a bacterial infection. In accordance with the IDSA guidelines [22], diagnosis of CNS infections (meningitis, ventriculitis) is based on a positive culture or a positive PCR. Antibiotics are never continued if all final values (cultures or PCR) are negative.

Broad-range 16S rDNA PCR is not routinely performed; it is reserved for questionable cases for whom the clinical condition raises suspicion of an infection; yet, the culture is negative, and the patient recently received antibiotics which could lead to a false negative culture secondary to partial treatment.

It is important to state that during the study period, none of the patients treated by this algorithm had a relapse of infection attributed to antibiotic stopping. Also, LCSF values did not alter any of our treatment decisions. Thus, we considered patients not receiving a full treatment course (as supported by a negative culture or PCR results), to be "not infected".

Collected data included demographics, CSF results (RBC, WBC, %PMN, glucose, protein, LCSF, gram stain, culture, and PCR if done). Specific data points were recorded:

- Whether the patient underwent a neurosurgical procedure within 1 month prior to CSF sample.
- Whether the patient underwent a traumatic brain injury within 1 month prior to CSF sample.
- Extent of bloody CSF contamination during surgery. This was arbitrarily categorized as minimal (e.g., following resection of a cortically based lesion), moderate (e.g., following resection of a ventricular lesion), and significant (e.g., following hemispherotomy or any other ventricular surgery associated with significant ventricular bleed). Categorization was based on the operation report and postoperative imaging.
- Recent (< 48 h) treatment with antibiotics (taking into consideration "partial treatment").
- Recent (< 48 h) endoscopic procedure (as we use Ringer Lactate for irrigation).
- Origin of CSF sample. This was categorized as lumbar (e.g., via an LP or a lumbar drain), pseudomeningocele (e.g., PM, for tapping of subcutaneous fluid collections in the cranial or spinal regions), and ventricular (e.g., transfontanelle tap, EVD, externalized shunt, shunt, or Ommaya tap)
- Indication for CSF sampling. This was categorized as suspected infection or other, such as: mechanical

evaluation of shunts, routine CSF samples done for patients with drains, or any other indication not related to suspicion of an infection.
- Existence of residual tumor or leptomeningeal spread.

Multiple samples

As many patients had multiple CSF samples taken, and in order to avoid a bias by recurrent samples from the same patient, we arbitrarily decided to use the "first CSF" sample per patient. However, we did include additional samples if they were more than 1 month distant from the previous included sample.

Lactate measurement technique

All CSF samples were analyzed using the RAPIDPoint® 500 (Siemens). This system is typically used for blood gas analysis. Thus, an evaluation of this system for CSF lactate measurement was performed, by analyzing 19 CSF samples, using both the above system and a standardized verified technique (Beckman coulter reagent, using the Advia® 2400, Siemens). A full description of the measurement techniques is supplied in Appendix 1.

Agreement between measurement techniques was observed using interclass correlation coefficient (ICC) for an absolute agreement. Spearman's correlation coefficient was used to evaluate the correlation between both techniques, and "one sample *t* test" was used to compare the difference between methods, to 0.

There was an excellent agreement (ICC = 0.964, $P < 0.001$) and high correlation ($r = 0.951$, $p < 0.001$), between both methods. There was no significant difference between methods (mean difference = 0.81, $p = 0.159$). Scatter plot and Bland-Altman plot are presented in Appendix 2 and 3 (for each appendix, A = lactate measured using RAPIDPoint® 500, and B = lactate measured using Advia® 2400).

Statistical analysis

Data was tabulated in an Excel spreadsheet. SPSS software was used for all statistical analyses (IBM SPSS statistics, version 22, IBM Corp., 2013, Armok, NY, USA). Categorical variables were reported as number and percentage. Continuous variables were evaluated for normal distribution using a histogram and reported as median and interquartile range (IQR). Correlations between continuous variables were evaluated using Spearman's correlation coefficient. Lactate was compared between categorical variables using Mann-Whitney test or Kruskal-Wallis test. All statistical tests were two tailed, and p value less than 0.05 was considered significant.

Results

Over a 26-month period, 450 LCSF samples were collected from 162 pediatric patients, of which 215 samples were analyzed (following the criteria described in Methods). After categorizing the samples according to their origin, we included 49, 25, and 141, from the lumbar, PM, and ventricular regions, respectively. Sixteen of the included samples (7.4%, from 12 patients) were defined as infected (according to the mentioned criteria): 2 (4%), 4 (16%), and 10 (7%), from lumbar taps, PM, and ventricular origin, respectively (Table 1).

A total of 11 cases underwent an endoscopic procedure within 48 h of CSF sampling: 3, 0, and 8 from the lumbar, PM, and ventricular origin, respectively.

LCSF displayed a significant positive correlation with other CSF parameters, such as WBC, %PMN, and protein, and inversely with glucose levels. This was true regardless of the origin of the CSF sample (lumbar, PM, or ventricular) (Table 2).

When correlating between LCSF levels and infection, LCSF was significantly increased only when the CSF sample was from a ventricular origin (as opposed to lumbar and PM) (Table 3, Fig. 1).

Despite the correlation between infection and LCSF level in the ventricular group, lactate could not sufficiently discriminate between those with or without infection (AUC = 0.761, Fig. 2), as for no LCSF value were both sensitivity and specificity greater than 70%.

Table 1 Infective organisms, origin of CSF sample, and lactate levels

Infected organism	Sample origin	CSF lactate levels (mmol/L)
MSSA	LP	11.8
Staph epidermidis	LP	1.83
Klebsiela pneumonia	PM	9.25
Brucella	PM	1.58
MSSA	PM	13.2
Pseudomonas aeruginosa	PM	8.3
Staph epidermidis	Ventricular	3.06
Hemophillus influenza	Ventricular	10.6
Hemophillus influenza	Ventricular	8.21
Pseudomonas aeruginosa	Ventricular	9.03
Pseudomonas aeruginosa	Ventricular	14.1
MRSA	Ventricular	6.68
Enterococcus fecalis	Ventricular	9.4
Staph epidermidis	Ventricular	3.29
Staph epidermidis	Ventricular	1.24
Strep Viridans	Ventricular	6.41

MSSA methicillin-sensitive staph aureus, *MRSA* methicillin-resistant staph aureus

Table 2 Correlation between CSF lactate and other CSF parameters according to sampling origin

	Lumbar			Pseudomeningocele			Ventricular		
	N	*R*	*p*	*N*	*r*	*p*	*N*	*R*	*P*
WBC (cells/μL)	47	*0.73*	*< 0.001*	20	*0.495*	*0.027*	118	*0.687*	*< 0.001*
%PMN	42	*0.43*	*0.005*	20	*0.551*	*0.012*	94	*0.44*	*< 0.001*
RBC (cells/μL)	41	0.11	0.48	20	− 0.258	0.272	99	*0.337*	*0.001*
Glucose (mg/dL)	48	*− 0.64*	*< 0.001*	25	*− 0.5*	*0.011*	140	*− 0.407*	*< 0.001*
Protein (mg/dL)	48	*0.76*	*< 0.001*	25	*0.581*	*0.002*	140	*0.634*	*< 0.001*

Italic values highlight those with a significant correlation

WBC white blood cells, *PMN* polymorphonuclear cells, *RBC* red blood cells

Within both the lumbar and ventricular groups, LCSF correlated with recent neurosurgical surgery (Table 3). Additionally, lactate levels correlated with extent of blood contamination during surgery (as defined previously in Methods). Within the lumbar group, LCSF levels correlated with the indication for CSF sampling (if suspected of infection), but not with actual infection. Within the ventricular group, LCSF correlated with residual tumor and with recent antibiotic treatment (as well as actual infection). Within the ventricular group, recent endoscopic procedures did not significantly affect LCSF.

Of the CSF samples from ventricular origins taken from patients with no recent surgeries, 9 of 93 cases had an infection. LCSF significantly correlated with infection (8.21 (2.26–10) vs 1.92 (1.33–2.51), $p = 0.005$). Only 1 of 48 patients with ventricular origin CSF and recent surgeries had an infection; thus, no statistical analysis was performed.

Within the PM group, LCSF levels did not significantly correlate with any of the evaluated parameters (Table 3).

When comparing LCSF levels between all three origin groups, we found no significant difference between the lumbar and ventricular groups; however, levels were significantly higher in the PM group (Table 4). Interestingly, a similar pattern was seen when comparing RBC in the CSF between all three groups (Table 4).

Discussion

This is the first study evaluating the role of CSF lactate levels in differentiating between infected and non-infected CSF, focusing exclusively on neurosurgical children. Our results suggest several important points:

1. LCSF levels correlated with infection when taken from a ventricular origin.
2. LCSF levels did not correlate with infection when sampled from PM.
3. LCSF levels are influenced by many "surgical" factors, such as recent surgery and contamination of CSF by blood and debris.

Table 3 CSF lactate levels (mmol/L) according to sampling origin and various parameters. In case of less than three patients per category, all values are stated

CSF source		Lumbar			Pseudomeningocele			Ventricular		
		N	Median (IQR)	P	N	Median (IQR)	P	N	Median (IQR)	p
Indication	Susp infection	31	*2.73 (1.69–4.61)*	*0.008*	16	4.12 (2.89–7.37)	0.98	70	2.48 (1.64–3.72)	0.31
	Other	18	*1.65 (1.18–2.32)*		9	3.55 (3.21–6.29)		71	2.27 (1.56–3.48)	
Recent NS procedure	No	19	*1.6 (1.22–2.43)*	*0.005*	7	5.1 (0–9.25)	0.39	93	*1.99 (1.48–2.87)*	*< 0.001*
	Yes	30	*2.85 (1.69–4.62)*		18	3.77 (3.18–5.6)		48	*3.45 (2.34–4.89)*	
CSF blood at surgery	Clean	12	*1.69 (1.22–3.09)*	*0.014*	8	3.9 (3.46–4.29)	0.78	7	*2.18 (1.72–3.8)*	*0.054*
	Mild	13	*3 (2.15–4.81)*		9	3.55 (3–6.96)		21	*3.44 (2.3–4.03)*	
	Mod-significant	4	*4.95 (3.18–6.13)*		1	3.25		21	*4.31 (2.78–6.4)*	
Residual tumor	No	42	1.99 (1.36–3.43)	0.44	23	3.83 (3.17–5.5)	0.2	111	*2.04 (1.56–3.23)*	*< 0.001*
	Yes	7	3 (1.3–5.46)		2	5.93, 6.96		30	*3.75 (2.37–6.39)*	
Recent antibiotics	No	40	1.99 (1.3–3.09)	0.205	20	3.9 (2.91–6.47)	0.57	73	*1.89 (1.42–2.75)*	*< 0.001*
	Yes	9	3.55 (1.69–4.93)		5	4.27 (3.31–9.34)		68	*3.02 (2.07–4.52)*	
Infection	No	47	2.02 (1.33–3.55)	0.357	21	3.83 (3.17–5.3)	0.18	131	*2.27 (1.61–3.44)*	*0.006*
	Yes	2	1.83, 6.81		4	8.77 (3.26–12.19)		10	*7.31 (2.66–9.7)*	

Italic values highlight those with a significant correlation

NS neurosurgical

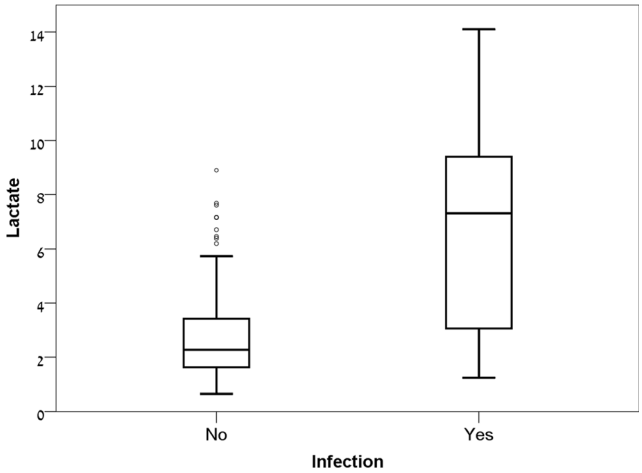

Fig. 1 Box plot of lactate levels in the infected and non-infected groups in the ventricular origin samples

4. LCSF levels correlated closely with other commonly tested CSF parameters such as WBC, %PMN, glucose, and protein.
5. LCSF levels could not sufficiently discriminate between those with or without infection, possibly due to confounding factors such as recent surgery and contamination of the CSF with blood and other surgical debris.

Differentiating between infected and non-infected CSF in a child with a history of neurosurgical procedures is not trivial [6, 13, 17]. Fever, headache, vomiting, irritability, somnolence, and nuchal rigidity may often be part of a postoperative course and do not necessarily indicate an active CSF infection [6, 7]. CSF parameters such as cell count, glucose, and protein levels are all affected by recent surgery, due to significant shifts in CSF volume (drainage and irrigation), spillage of "surgical debris" such as blood and tissue particles, or by a postoperative non-infectious inflammatory reaction to any of the above [7, 17]. Additionally, many children are treated during surgery or for a few days after, either with antibiotics, affecting the reliability of the CSF cultures, and/or with steroids, affecting the immune response to infection and inflammation. Thus, differentiating between infected and non-infected CSF based on clinical condition and/or standard CSF parameters may be of limited value [13].

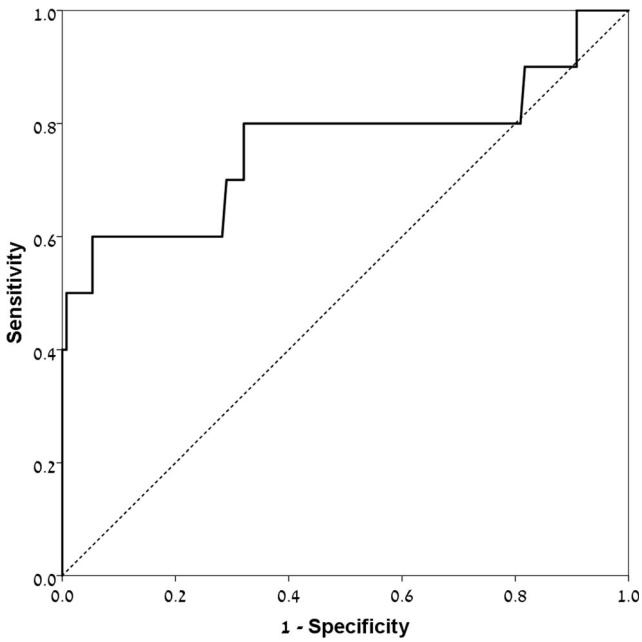

Fig. 2 ROC curve for LCSF taken from ventricular samples

LCSF testing has been used in the evaluation of spontaneous meningitis to differentiate between bacterial and aseptic meningitis in children and adults [11, 18]. Lactate is produced by certain bacteria, anaerobic metabolism of the brain tissue caused by hypoperfusion, as well as various cytokines [14]. It has been shown that LCSF has a higher sensitivity, specificity, positive predictive value, and negative predictive value compared to other conventional measures such as glucose, protein, and cell count and differentiation [11, 24]. Other para-meningeal infections may increase LCSF levels too [2, 12]. However, it has been shown that treatment with antibiotics may alter LCSF in spontaneous meningitis and that a low LCSF in treated patients does not rule out bacterial meningitis [2, 18].

Despite its encouraging role in differentiating bacterial from non-bacterial spontaneous meningitis, LCSF has been shown to be affected by several factors, which potentially, as suggested by our results, would affect its role in patients following neurosurgical procedures. Based on prior publications, the effect of CSF contaminated by blood on LCSF levels is uncertain. Begovac et al. stated that adding a blood drop to a CSF sample does not alter LCSF levels [1]. But others have shown that LCSF levels increase following in vitro and in vivo subarachnoid hemorrhage [8, 9, 19, 20]. LCSF levels in bloody CSF increased even more when blood was contaminated for at least 6 h, especially when the CSF sample was also exposed to air [23]. In patients with intraventricular hemorrhage that were sampled from an external ventricular drain, LCSF levels had a positive predictive value for CSF infection of 60%, and a negative predictive value of 100% [25]. In addition, LCSF levels are known to increase in several non-infectious clinical scenarios, such as stroke [5, 9], seizures [3, 4, 12], head injury [12], and hypoglycemic coma [27]. Nevertheless, in adult neurosurgical patients, LCSF levels have been shown to correlate with bacterial CNS infections, with a high sensitivity, specificity, positive, and negative predictive values [10, 14–16, 21, 26, 28]. Table 5 summarizes the known literature regarding LCSF following neurosurgical procedures.

Generally, most publications have focused on adult patients with suspected meningitis [10, 14–16, 21, 28], where CSF was sampled from lumbar taps (LP) [10, 14–16], and LCSF was determined to differentiate bacterial from non-bacterial infections. LCSF at levels of 3.45–5.9 mmol/l and above were significantly correlated with bacterial infections [10, 14–16, 28]. There was no correlation between LCSF levels and time from

Table 4 Comparison of CSF lactate and RBC according to sampling origin

	CSF lactate (mmol/L)			RBC in CSF (cells/μL)		
	N	Median (IQR)	*P*	*N*	Median (IQR)	*P*
PM	25	*3.97 (3.17–6.29)*	*< 0.001*	20	*716 (32–1834)*	*0.005*
Lumbar	49	*2.02 (1.35–3.59)*		41	*61 (0–383)*	
Ventricular	141	*2.35 (2.35–3.57)*		99	*14 (0–488)*	

Italic values highlight those with a significant correlation

PM pseudomeningocele, *RBC* red blood cells

surgery [14]. In one publication, LCSF levels did not correlate with RBC count in the CSF [16]. However, quite a few significant factors were not clear from many of the publications, including what surgical procedures were performed, was the CSF contaminated with blood products, and whether patients were pretreated with antibiotics or steroids [10, 14–16, 21, 28].

As stated, our data is the first focusing on neurosurgical children, some following recent surgery of various extents, and some with no recent surgery. We also carefully classified the origin point of the CSF samples (lumbar taps, ventricular sampling, and PM punctures) in a clearer reflection of daily clinical scenarios. There are no other studies published regarding possible correlations between LCSF levels and other surgical factors such as tissue destruction, ischemia, residual tumor, and presence of blood products in the CSF following surgery. Current literature also focuses on patients with suspected infections, comparing infected CSF to non-infected CSF in these patients, as opposed to our data, which also includes patients with no suspicion of infection.

Limitations

Our statistical analysis was limited by the following factors:

- While we began with a large number of CSF samples, once we subdivided the group according to CSF origin the numbers are relatively small.
- Surgical cases included various pathologies, such as tumors (benign and malignant), epilepsy related, and others.
- We had no baseline LCSF levels. Potentially, hydrocephalus, presence of certain brain tumors and in specific locations, may alter LCSF levels.
- Surgery may alter LCSF levels. We could not quantify the degree of tissue destruction. As noted above, tissue ischemia may lead to an increase in LCSF. Endoscopic procedures, especially those associated with irrigation with Ringer Lactate, may shift LCSF to a higher baseline too.
- Due to the small number of infections, and limited CSF samples per infected case, we could not evaluate the impact of bacteria type, or effect of antibiotics, on LCSF levels. For the same reasons, natural history of LCSF over time could not be analyzed.

Despite data being mostly based on laboratory results (and thus not affected by the retrospective nature of the study), clinical data was collected retrospectively. We believe that the impact of this on the results was not significant because infections (as we defined in the methods) are documented in real time, and there was no infectious flare-up (or misdiagnosed infections) using our protocols, as stated in the methods.

In addition, we analyzed events (i.e., laboratory tests) and not cases. Thus, some cases were included several times due to multiple CSF sampling. We limited the number of samples included to 1 per month; however, some patients were included 2 or 3 times. This may potentially skew the results. We believe any bias was minimal because of the rarity of this condition, and because even if patients were represented a more than one time, each event represents a distinct and unrelated event.

Table 5 Current literature regarding LCSF in post neurosurgical patients

Paper	Number of patients	Origin of CSF	Indication for CSF sampling	LCSF cutoff
Leib (1999)	73 (adults)	LP	Suspected infection	4 mmol/L
Tavares (2006)	28 (children and adults)	LP or EVD	Suspected infection	49 mg/dL = 5.4 mmol/L
Grille (2012)	46 (adults)	LP	Suspected infection	5.9 mmol/L
Maskin (2013)	79 (adults)	LP	Suspected infection	4 mmol/L
Li (2014)	178 (adults)	LP	Suspected infection	3.45 mmol/L
Zhang (2017)	8524 (children and adults)	Unknown	Suspected infection	3.6 mmol/L

Conclusions

LCSF levels are influenced by many factors such as the source of sample, recent surgery, and subarachnoid or ventricular blood secondary to surgery. LCSF levels correlate with other CSF parameters such as cell counts and glucose levels. The added value of LCSF for diagnosing CSF infections in children with a history of neurosurgical procedures is unclear and may be influenced by the extent of blood in the CSF. Thus, based on the current data, we recommend further studying LCSF levels and its correlation with other surgical parameters.

Acknowledgments We thank Tomer Ziv-Baran, PhD, for assistance with statistical analysis, and Mrs. Adina Sherer for editorial assistance.

Funding No funding was given for any part of this study.

Compliance with ethical standards

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

References

1. Begovac J, Bace A, Soldo I, Lehpamer B (1991) Lactate and glucose in cerebrospinal fluid heavily contaminated with blood. Acta Med Croatica 45:341–345
2. Brook I, Bricknell KS, Overturf GD, Finegold SM (1978) Measurement of lactic acid in cerebrospinal fluid of patients with infections of the central nervous system. J Infect Dis 137:384–390
3. Brooks BR, Adams RD (1975) Cerebrospinal fluid acid-base and lactate changes after seizures in unanesthetized man II. Alcohol withdrawal seizures. Neurology 25:943–948
4. Brooks BR, Adams RD (1975) Cerebrospinal fluid acid-base and lactate changes after seizures in unanesthetized man. I. Idiopathic seizures. Neurology 25:935–942
5. Busse O, Hoffmann O (1983) CSF lactate and CT findings in middle cerebral artery infarction. A comparative study. Stroke 14:960–963
6. Carmel PW, Fraser RA, Stein BM (1974) Aseptic meningitis following posterior fossa surgery in children. J Neurosurg 41:44–48
7. Forgacs P, Geyer CA, Freidberg SR (2001) Characterization of chemical meningitis after neurological surgery. Clin Infect Dis 32: 179–185
8. Froman C, Smith AC (1967) Metabolic acidosis of the cerebrospinal fluid associated with subarachnoid haemorrhage. Lancet 1:965–967
9. Fujishima M, Sugi T, Choki J, Yamaguchi T, Omae T (1975) Cerebrospinal fluid and arterial lactate, pyruvate and acid-base balance in patients with intracranial hemorrhages. Stroke 6:707–714
10. Grille P, Torres J, Porcires F, Bagnulo H (2012) Value of cerebrospinal fluid lactate for the diagnosis of bacterial meningitis in postoperative neurosurgical patients. Neurocirugia (Astur) 23:131–135
11. Huy NT, Thao NT, Diep DT, Kikuchi M, Zamora J, Hirayama K (2010) Cerebrospinal fluid lactate concentration to distinguish bacterial from aseptic meningitis: a systemic review and meta-analysis. Crit Care 14:R240
12. Jordan GW, Statland B, Halsted C (1983) CSF lactate in diseases of the CNS. Arch Intern Med 143:85–87
13. Kim YS, Pons VG (1994) Infections in the neurosurgical intensive care unit. Neurosurg Clin N Am 5:741–754
14. Leib SL, Boscacci R, Gratzl O, Zimmerli W (1999) Predictive value of cerebrospinal fluid (CSF) lactate level versus CSF/blood glucose ratio for the diagnosis of bacterial meningitis following neurosurgery. Clin Infect Dis 29:69–74
15. Li Y, Zhang G, Ma R, Du Y, Zhang L, Li F, Fang F, Lv H, Wang Q, Zhang Y, Kang X (2015) The diagnostic value of cerebrospinal fluids procalcitonin and lactate for the differential diagnosis of post-neurosurgical bacterial meningitis and aseptic meningitis. Clin Biochem 48:50–54
16. Maskin LP, Capparelli F, Mora A, Hlavnicka A, Orellana N, Diaz MF, Wainsztein N, Del Castillo M (2013) Cerebrospinal fluid lactate in post-neurosurgical bacterial meningitis diagnosis. Clin Neurol Neurosurg 115:1820–1825
17. Ross D, Rosegay H, Pons V (1988) Differentiation of aseptic and bacterial meningitis in postoperative neurosurgical patients. J Neurosurg 69:669–674
18. Sakushima K, Hayashino Y, Kawaguchi T, Jackson JL, Fukuhara S (2011) Diagnostic accuracy of cerebrospinal fluid lactate for differentiating bacterial meningitis from aseptic meningitis: a meta-analysis. J Inf Secur 62:255–262
19. Shannon DC, Shore N, Kazemi H (1972) Acid-base balance in hemorrhagic cerebrospinal fluid. Neurology 22:585–589
20. Sugi T, Fujishima M, Omae T (1975) Lactate and pyruvate concentrations, and acid-base balance of cerebrospinal fluid in experimentally induced intracerebral and subarachnoid hemorrhage in dogs. Stroke 6:715–719
21. Tavares WM, Machado AG, Matushita H, Plese JP (2006) CSF markers for diagnosis of bacterial meningitis in neurosurgical postoperative patients. Arq Neuropsiquiatr 64:592–595
22. Tunkel AR, Hasbun R, Bhimraj A, Byers K, Kaplan SL, Michael Scheld W, van de Beek D, Bleck TP, Garton HJ, Zunt JR (2017) 2017 Infectious Diseases Society of America's clinical practice guidelines for healthcare-associated Ventriculitis and meningitis. Clin Infect Dis 64:701–706
23. Venkatesh B, Morgan TJ, Boots RJ, Hall J, Siebert D (2003) Interpreting CSF lactic acidosis: effect of erythrocytes and air exposure. Crit Care Resusc 5:177–181
24. Viallon A, Desseigne N, Marjollet O, Birynczyk A, Belin M, Guyomarch S, Borg J, Pozetto B, Bertrand JC, Zeni F (2011) Meningitis in adult patients with a negative direct cerebrospinal fluid examination: value of cytochemical markers for differential diagnosis. Crit Care 15:R136
25. Wong GK, Poon WS, Ip M (2008) Use of ventricular cerebrospinal fluid lactate measurement to diagnose cerebrospinal fluid infection in patients with intraventricular haemorrhage. J Clin Neurosci 15: 654–655
26. Xiao X, Zhang Y, Zhang L, Kang P, Ji N (2016) The diagnostic value of cerebrospinal fluid lactate for post-neurosurgical bacterial meningitis: a meta-analysis. BMC Infect Dis 16:483
27. Yao H, Sadoshima S, Nishimura Y, Fujii K, Oshima M, Ishitsuka T, Fujishima M (1989) Cerebrospinal fluid lactate in patients with diabetes mellitus and hypoglycaemic coma. J Neurol Neurosurg Psychiatry 52:372–375
28. Zhang Y, Xiao X, Zhang J, Gao Z, Ji N, Zhang L (2017) Diagnostic accuracy of routine blood examinations and CSF lactate level for post-neurosurgical bacterial meningitis. Int J Infect Dis 59:50–54