



# Cerebrospinal Fluid and Blood Lactate and Procalcitonin for Diagnosis of Post-neurosurgical Bacterial Meningitis

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## Abstract

**Objective** To investigate the diagnostic value of lactate and procalcitonin levels in cerebrospinal fluid (CSF) and blood for the diagnosis of post-neurosurgical bacterial meningitis (PNBM).

**Materials and Methods** A 2-year prospective study was conducted at the Faculty of Medicine, Vajira Hospital, Bangkok, Thailand. Data were collected on patient demographics, underlying disease, time to suspected PNBM, operative time, preoperative antibiotic use, blood lactate and procalcitonin levels, and CSF cell count, cell differentiation, protein, glucose, lactate, and procalcitonin levels. Sensitivity, specificity, accuracy, positive predictive value, and negative predictive value were calculated using Fisher's exact test.

**Results** A CSF lactate level greater than 4 mmol/L showed a sensitivity of 82.2%, specificity of 62.5%, positive predictive value of 92.5%, negative predictive value of 38.5%, and accuracy of 39.62%. A CSF procalcitonin level greater than 0.075 ng/mL showed a sensitivity of 100%, specificity of 0%, positive predictive value of 100%, negative predictive value of 0%, and accuracy of 100%. A blood lactate level greater than 2 mmol/L showed a sensitivity of 17.8%, specificity of 100%, positive predictive value of 100%, negative predictive value of 17.8%, and accuracy of 43.24%. A blood procalcitonin level greater than 0.25 ng/mL showed a sensitivity of 40%, specificity of 50%, positive predictive value of 81.8%, negative predictive value of 12.9%, and accuracy of 44.23%. CSF lactate >5.25 mmol/L had a specificity of 100%, and CSF/blood lactate ratio >7.07 had a specificity of 100% for PNBM diagnosis.

**Conclusion** CSF lactate and the CSF/blood lactate ratio are useful in the diagnosis of PNBM. However, CSF procalcitonin, blood lactate, blood procalcitonin, and the CSF/blood procalcitonin ratio are not reliable for diagnosing PNBM. CSF lactate greater than 5.25 mmol/L and CSF/blood lactate ratio greater than 7.07 are highly specific for the diagnosis of PNBM.

## Keywords

- ▶ meningitis
- ▶ cerebrospinal fluid
- ▶ lactate
- ▶ procalcitonin
- ▶ neurosurgical procedures

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## Introduction

Post-neurosurgical bacterial meningitis (PNBM) is a serious complication following neurosurgical procedures. Delayed diagnosis can lead to increased patient morbidity and mortality. The mortality rate for bacterial meningitis is reported to be approximately 25%.<sup>1,2</sup> Prompt and accurate diagnosis is crucial for the timely administration of appropriate antibiotics, which can improve patient outcomes, reduce mortality and morbidity, enhance quality of life, and decrease the burden on health care providers and the health care system.

Common clinical manifestations of PNBM include fever, headache, nuchal rigidity, and decreased level of consciousness. At Vajira Hospital, the incidence of PNBM is approximately 3% annually. The gold standard for diagnosis involves cerebrospinal fluid (CSF) analysis, including cell count, glucose level (compared to serum glucose), and culture. Specifically, international diagnostic criteria for bacterial meningitis include: CSF glucose concentration <40 mg/dL, CSF to serum glucose ratio  $\leq 0.4$ , protein concentration >200 mg/dL, and white blood cell (WBC) count (predominantly neutrophils) of approximately 1,000/mL.<sup>3–5</sup> Positive bacterial CSF culture or Gram stain is also a key diagnostic indicator. However, lumbar puncture, the procedure used to obtain CSF, is often perceived by patients as dangerous and uncomfortable. Therefore, maximizing the diagnostic yield of each CSF analysis is important. In cases where initial CSF results are unclear, repeat lumbar punctures may be necessary. This study investigates the role of lactate and procalcitonin levels in CSF and blood as potential diagnostic adjuncts for PNBM.

Previous research has explored the utility of CSF lactate in the diagnosis of PNBM. In a 1998 retrospective study, Tang et al<sup>1</sup> compared CSF lactate with the CSF/blood glucose ratio and found that CSF lactate >4 mmol/L was more accurate than a CSF/blood glucose ratio <0.4. This finding is referenced in the Infectious Diseases Society of America guidelines<sup>2</sup> for managing suspected PNBM. In 2010, Huy et al,<sup>3</sup> in a systematic review and meta-analysis, demonstrated the usefulness of CSF lactate in differentiating bacterial from aseptic meningitis. Maskina et al<sup>4</sup> in a 2013 prospective study reported that a CSF lactate cutoff of >4 mmol/L had a sensitivity of 97% (95% confidence interval [CI]: 84–100%), a specificity of 78% (95% CI: 64–89%), a positive predictive value (PPV) of 76% (95% CI: 60–88%), and a negative predictive value (NPV) of 97% (95% CI: 86–100%) for diagnosing PNBM. In 2015, Li et al<sup>5</sup> retrospectively studied both CSF lactate and procalcitonin in PNBM, establishing cutoff values of 0.075 ng/mL for CSF procalcitonin (sensitivity 68%, specificity 72.7%) and 3.45 mmol/L for CSF lactate (sensitivity

90%, specificity 84.6%). CSF lactate has also been investigated in the diagnosis of community-acquired bacterial meningitis.<sup>6</sup>

While previous studies, primarily retrospective, have suggested that CSF lactate is more accurate than procalcitonin in diagnosing PNBM, there is a lack of prospective data, particularly from Southeast Asian populations. This prospective study aims to evaluate the diagnostic accuracy of CSF and blood lactate and procalcitonin levels in a Thai population.

## Materials and Methods

This prospective study was conducted from 17 January 2017 to December 2018, at the Faculty of Medicine, Vajira Hospital, Navamindradhiraj University. Data were collected from patients who underwent neurosurgical procedures and subsequently developed suspected PNBM. CSF samples were analyzed for cell count, cell differentiation, protein, glucose, lactate, procalcitonin, Gram stain, and culture. Simultaneous blood samples were collected for glucose, lactate, and procalcitonin levels. CSF and blood glucose, lactate, and procalcitonin ratios were calculated.

Inclusion criteria were patients presenting with signs and symptoms suggestive of bacterial meningitis (fever, headache, nuchal rigidity) or decreased level of consciousness following a neurosurgical procedure. Exclusion criteria were pre-existing meningitis prior to neurosurgery, pregnancy, and age younger than 15 years. Collected data included patient demographics (age, sex), presenting symptoms, underlying diseases, surgical procedures, preoperative antibiotic use, presence of catheter in neurological tissue, postoperative steroid administration, time from surgery to suspected PNBM, operative time, and CSF and blood lactate and procalcitonin levels.

Patients with suspected PNBM were classified into three groups (► **Table 1**):

- Proven PNBM (PrNBM): positive bacterial CSF culture or Gram stain, plus CSF WBC count  $\geq 100$ /mL and/or hypoglycorrhachia (CSF glucose <40 mg/dL or CSF:plasma glucose ratio <0.4).
- Presumed PNBM (PeNBM): patients who received antibiotic 24 hours before CSF sample, plus CSF WBC count  $\geq 500$ /mL and/or CSF:plasma glucose ratio <0.5.
- No PNBM (NNBM): patients not meeting the criteria for PrNBM or PeNBM.

The diagnostic performance of CSF lactate (>4 mmol/L), blood lactate (>2 mmol/L), CSF procalcitonin (>0.075 ng/mL), and blood procalcitonin (>0.25 ng/mL) was

**Table 1** Classification of post-neurosurgical bacterial meningitis

Classification	Culture or Gram stain	WBC count (cells/mL)	CSF:plasma glucose ratio
PrNBM	+	$\geq 100$	<0.4
PeNBM	–	$\geq 500$	<0.5
NNBM	–	–	–

Abbreviations: CSF, cerebrospinal fluid; NNBM, no post-neurosurgical bacterial meningitis; PeNBM, presumed post-neurosurgical bacterial meningitis; PrNBM, proven post-neurosurgical bacterial meningitis; WBC, white blood cell.

evaluated using these criteria as the gold standard. Sensitivity, specificity, accuracy, PPV, and NPV were calculated using Fisher's exact test with SPSS version 22.

## Results

A total of 53 patients with suspected PNBM were included in the study. There were 27 males (50.94%) and 26 females (49.06%), with a mean age of 55 years. The most common presenting symptom was fever (96.2%). The most common underlying disease was vascular malformation (67.92%), with clipping of aneurysm being the most frequent surgical procedure (43.40%). The majority of patients (90.57%) received preoperative cefazolin. Most operations (45.28%) lasted less than 3 hours. The median time to suspected PNBM was 5 days post-surgery (39.62%). CSF lactate levels were  $>4$  mmol/L in 40 patients (75.47%), and CSF procalcitonin levels were  $>0.075$  ng/mL in all 53 patients (100%). Blood lactate levels were  $>2$  mmol/L in eight patients (15.1%). Blood procalcitonin levels were  $>0.25$  ng/mL in 22 patients (41.5%). The combined PrNBM and PeNBM groups comprised 45 patients (84.9%; ► **Tables 2** and **3**).

Data collected from the PrNBM group showed positive cultures in four patients. Two additional patients had positive Gram stains but negative cultures. Positive cultures yielded *Acinetobacter baumannii* ( $n=2$ ), *Staphylococcus haemolyticus* ( $n=1$ ), and *Klebsiella pneumoniae* ( $n=1$ ). Patient characteristics among these cases included neurological device insertion ( $n=3$ ), tumors ( $n=3$ ), vascular malformation ( $n=1$ ), trauma ( $n=1$ ), and shunt revision ( $n=1$ ); ► **Table 4**).

This study showed that for a CSF lactate cut-off of  $>4$  mmol/L, a sensitivity was 82.2%, specificity was 62.5%, PPV

**Table 2** Demographic patient data

Demographic	No.	%
<b>1. Gender</b>		
Male	27	50.9
Female	26	49.1
<b>2. Clinical</b>		
Fever	48	90.6
Decreased level of consciousness	5	9.4
Headache	0	0
<b>3. Underlying disease</b>		
Hypertension	23	43.4
Diabetic mellitus	4	7.5
Dyslipidemia	5	9.4
Other	8	15.1
<b>4. Disease</b>		
Vascular malformation	36	67.9
Tumor	11	20.8
Trauma	4	7.5
Hydrocephalus	2	3.8

(Continued)

**Table 2** (Continued)

Demographic	No.	%
<b>5. Operation</b>		
Clipping of aneurysm	23	43.4
Clot removal	11	20.8
Tumor removal	8	15.1
Ventriculostomy	5	9.4
Excision arteriovenous malformation	2	3.8
Shunt insertion and removal	2	3.8
Laminectomy to remove tumor	1	1.9
Repair CSF leakage	1	1.9
<b>6. Preoperative antibiotic</b>		
Cefazolin	48	90.6
Fosfomycin	4	7.5
Vancomycin	1	1.9
<b>7. Foreign device</b>		
None	42	79.2
Ventriculostomy	8	15.1
Lumbar drain	2	3.8
VP shunt	1	1.9
<b>8. Postoperative steroid</b>		
None	47	88.7
Yes	6	11.3
<b>9. Timing of operation (hours)</b>		
$\leq 3$	24	45.3
3–6	21	39.6
$\geq 6$	8	15.1
<b>10. CSF lactate (mmol/L)</b>		
$\geq 4$	40	75.5
$< 4$	13	24.5
<b>11. CSF procalcitonin (ng/mL)</b>		
$\geq 0.075$	53	100%
$< 0.075$	0	0
<b>12. Blood lactate (mmol/L)</b>		
$> 2$	8	15.1
$\leq 2$	45	84.9
<b>13. CSF procalcitonin (ng/mL)</b>		
$> 0.25$	22	41.5
$\leq 0.25$	31	58.5
<b>14. Outcome</b>		
PrNBM	6	11.32
PeNBM	39	73.58
NNBM	8	15.1

Abbreviations: CSF, cerebrospinal fluid; NNBM, no post-neurosurgical bacterial meningitis; PeNBM, presumed post-neurosurgical bacterial meningitis; PrNBM, proven post-neurosurgical bacterial meningitis; WBC, white blood cell.

**Table 3** Variable data, mean and SD

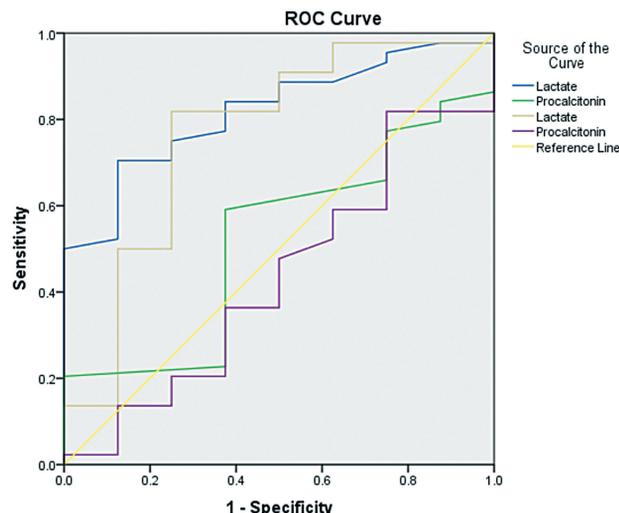
Variable	Mean/± SD
1. Age	55.56 years
2. Day for rule out meningitis	4.0–6.0 days
3. CSF lactate	3.55–6.575 mmol/L
4. CSF procalcitonin	3.55–6.75 ng/mL
5. Blood lactate	1.125–1.7 mmol/L
6. Blood procalcitonin	0.45–0.68 mmol/L

Abbreviations: CSF, cerebrospinal fluid; SD, standard deviation.

was 92.5%, NPV was 38.5%, and accuracy was 39.62%. For CSF procalcitonin >0.075 ng/mL, a sensitivity was 100%, specificity was 0%, PPV was 100%, NPV was 0%, and accuracy was 100%. Blood lactate >2 mmol/L demonstrated a sensitivity of 17.8%, specificity of 100%, PPV of 100%, NPV of 17.8%, and accuracy of 43.24%. Blood procalcitonin >0.25 ng/mL yielded a sensitivity of 40%, specificity of 50%, PPV of 81.8%, NPV of 12.9%, and accuracy of 44.23% (→ **Table 5**).

Results indicated that neither postoperative steroid administration ( $p = 0.219$ ) nor the presence of a foreign body catheter ( $p = 0.468$ ) significantly impacted the incidence of PNBM. A CSF lactate level exceeding 4 mmol/L was predictive of PNBM ( $p = 0.04$ ). In contrast, CSF procalcitonin >0.075 ng/mL ( $p = 0.859$ ), blood lactate >2.5 ng/mL ( $p = 0.447$ ), and blood procalcitonin >0.25 ng/mL ( $p = 0.447$ ) were not significant predictors of PNBM (→ **Fig. 1**).

In conclusion, CSF lactate >4 mmol/L demonstrated diagnostic performance with a sensitivity of 82.5% and a specificity of 62.5%. Evaluating a higher cut-off, CSF lactate >5 mmol/L achieved 100% specificity but only 50% sensitivity. A cut-off of



**Fig. 1** ROC curve of CSF lactate, CSF procalcitonin, blood lactate, and blood procalcitonin. CSF, cerebrospinal fluid; ROC, receiver-operating characteristic.

CSF lactate >4.45 mmol/L provided a sensitivity of 70% and a specificity of 87%. Consequently, a CSF lactate threshold of >4.45 mmol/L is suggested as the most effective for screening, while a threshold of >5.00 mmol/L is recommended for optimal diagnosis of PNBM (→ **Fig. 2**).

Subsequently, in patients with CSF lactate levels exceeding 5.00 mmol/L, the diagnostic utility of CSF/blood ratios was evaluated. The CSF/blood lactate ratio was significantly associated with PNBM ( $p < 0.00$ ). Conversely, the CSF/blood procalcitonin ratio did not demonstrate a significant association with PNBM ( $p = 0.652$ ). A CSF/blood lactate ratio greater than 7.07 yielded 100% specificity (→ **Figs. 3 and 4**).

**Table 4** Characteristic of patients with culturally proven bacterial meningitis following neurosurgery

Age(y)/sex	Indication for surgery	Foreign device	Microorganism isolated
63/M	Tumor	Ventriculostomy	<i>Acinetobacter baumannii</i>
41/F	Shunt malfunction	–	<i>Klebsiella pneumoniae</i>
40/F	Tumor	Ventriculoperitoneal shunt	<i>Staphylococcus haemolyticus</i>
40/F	Pseudotumor cerebri	Lumbar drain	<i>Acinetobacter baumannii</i>
47/M	Vascular malformation	–	– C/S, + Gram stain
59/F	Trauma	–	– C/S, + Gram stain

**Table 5** Summary and predictive value of CSF lactate levels and CSF procalcitonin level

Variable	CSF lactate level	CSF procalcitonin level	Blood lactate level	Blood procalcitonin level
Sensitivity	82.2%	100%	17.8%	40%
Specificity	62.5%	0%	100%	50%
Positive predictive value	92.5%	100%	100%	81.8%
Negative predictive value	38.5%	0%	17.8%	12.9%
Accuracy	39.62%	100%	43.24	44.23

Abbreviation: CSF, cerebrospinal fluid.

Coordinates of the Curve

Test Result Variable(s)	Positive if Greater Than or Equal To <sup>a</sup>	Sensitivity	1 - Specificity
Lactate	.700	1.000	1.000
	1.750	.977	1.000
	2.100	.977	.875
	2.450	.955	.750
	2.550	.932	.750
	2.650	.886	.625
	2.800	.886	.500
	2.950	.864	.500
	3.050	.841	.500
	3.250	.841	.375
	3.700	.818	.375
	4.050	.773	.375
	4.150	.750	.250
	4.250	.727	.250
	4.350	.705	.250
	4.450	.705	.125
	4.550	.659	.125
	4.800	.614	.125
	5.050	.568	.125
	5.150	.523	.125
	5.250	.500	.000
	5.350	.477	.000
	5.450	.455	.000
	5.600	.432	.000
	5.750	.386	.000
	5.850	.364	.000
	6.100	.341	.000
	6.400	.318	.000

Fig. 2 Coordinates of CSF lactate of sensitivity and specificity. CSF, cerebrospinal fluid.

Discussion

Our study demonstrates the accuracy of CSF lactate and the CSF/blood lactate ratio in diagnosing PNBM. To our knowledge, this represents the first prospective study on this topic conducted in Thailand.

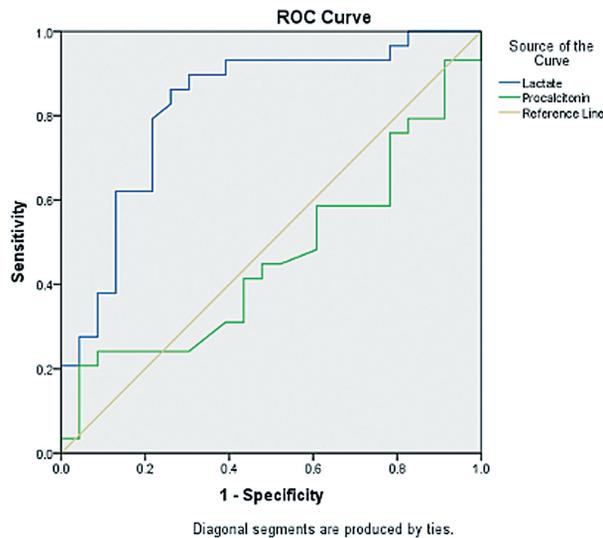


Fig. 3 ROC curve of CSF/blood lactate ratio and CSF/blood procalcitonin ratio. CSF, cerebrospinal fluid; ROC, receiver-operating characteristic.

Coordinates of the Curve

Test Result Variable(s)	Positive if Greater Than or Equal To <sup>a</sup>	Sensitivity	1 - Specificity
Lactate	132.33000	1.000	1.000
	135.88500	1.000	.957
	139.23000	1.000	.913
	145.00000	1.000	.870
	150.42500	1.000	.826
	152.42500	.866	.826
	169.58250	.866	.783
	185.44750	.931	.783
	186.86500	.931	.739
	190.00000	.931	.696
	207.00000	.931	.652
	222.50000	.931	.609
	232.00000	.931	.565
	242.72000	.931	.522
	248.89000	.931	.478
	256.47000	.931	.435
	261.48000	.931	.391
	267.58000	.897	.391
	272.78500	.897	.348
	275.16500	.897	.304
	282.93000	.862	.304
	289.26500	.862	.261
	295.83500	.828	.261
	312.50000	.793	.217
	337.50000	.759	.217
	355.00000	.690	.217
	365.71500	.655	.217
	377.21500	.621	.217
	391.50000	.621	.174
	403.50000	.621	.130
	408.50000	.552	.130
	412.85000	.517	.130
	420.35000	.483	.130
	428.12500	.448	.130
	432.29000	.414	.130
	441.56500	.379	.130
	484.00000	.379	.087
	523.28500	.345	.087
	534.28500	.310	.087
	551.25000	.276	.087
	586.75000	.276	.043
	618.00000	.241	.043
	655.50000	.207	.043
	707.00000	.207	.000
	791.50000	.130	.000
	946.50000	.103	.000
	1039.00000	.068	.000
	1591.43000	.034	.000
	2143.86000	.000	.000

Fig. 4 Coordinates of CSF/blood lactate ratio of sensitivity and specificity. CSF, cerebrospinal fluid.

The rationale for using CSF lactate stems from bacterial infection leading to acidosis.<sup>7-9</sup> Consequently, CSF lactate has been investigated since the 1920s to differentiate bacterial from viral meningitis, particularly in children.<sup>10,11</sup> Numerous studies have concluded that CSF lactate cut-off values between 3.5 and 4.0 mmol/L offer suitable specificity and sensitivity for diagnosing bacterial meningitis.<sup>12,13</sup> Furthermore, meta-analyses have explored the use of CSF lactate to distinguish bacterial meningitis from aseptic meningitis.<sup>3,14,15</sup>

Regarding post-neurosurgical patients, retrospective studies have investigated the use of CSF markers for

diagnosing PNBM, including one by Leib et al,<sup>6</sup> which analyzed data from 477 lumbar punctures. Leib et al reported that CSF lactate at 4.0 mmol/L performed better for diagnosis than the CSF/blood glucose ratio (cut-off 0.4). Our prospective study observed an even stronger association of both CSF lactate and the CSF/blood lactate ratio with PNBM diagnosis. Consistent with findings by Tavares et al,<sup>16</sup> who reported the utility of CSF glucose and CSF lactate in diagnosing PNBM, our results also demonstrate similar utility. Notably, our study supports the use of the CSF/blood lactate ratio for diagnosis even in patients who have received antibiotics or have negative CSF cultures, a finding corroborated by earlier research.<sup>17,18</sup>

It is important to note that CSF lactate levels can be influenced by the metabolism of red blood cells (RBCs) in the CSF, leading to elevated lactate in the presence of high RBC counts,<sup>19</sup> as observed in patients with subarachnoid hemorrhage from the study of Lindgren et al.<sup>20</sup> Thus, interpreting CSF lactate necessitates considering the CSF RBC count.<sup>21</sup> However, in our study, we found that CSF lactate levels were not significantly affected by the presence of RBCs, which aligns with findings from the Begovac et al study<sup>22</sup> and the Leib et al study.<sup>6</sup>

Nevertheless, a low CSF lactate level does not definitively rule out bacterial meningitis, as several factors can affect its accuracy. Clinical symptoms should therefore always be considered in diagnosis.<sup>23</sup> CSF lactate serves as an ancillary diagnostic tool. Other biomarkers, such as CD163,<sup>24</sup> C-reactive protein,<sup>25</sup> or heparin-binding protein,<sup>26</sup> may also be valuable aids in the diagnostic process.

In our study, CSF procalcitonin and CSF/blood procalcitonin ratio were not found to be useful for the diagnosis of PNBM. However, CSF procalcitonin has been shown elsewhere to be useful in diagnosing bacterial meningitis<sup>27</sup> and differentiating bacterial from viral infections.<sup>28</sup> Studies investigating spinal fluid pleocytosis and heparin-binding protein have also demonstrated utility in distinguishing bacterial meningitis from other forms of meningitis.

While CSF lactate is widely available, cost-effective, and validated as an adjunctive marker in PNBM, the applicability of procalcitonin remains considerably more restricted. In particular, procalcitonin testing—especially when performed in CSF—may be impractical in many low- and middle-income countries owing to its higher cost, requirements for specialized instrumentation, and the absence of regulatory approval for off-label application of CSF. Despite the present study demonstrating no significant diagnostic utility of either CSF or serum procalcitonin in PNBM, it remains essential to acknowledge these feasibility constraints and practical limitations when evaluating its potential role in clinical practice.

Advanced imaging techniques such as proton nuclear magnetic resonance-based metabolic imaging and spectroscopy can also be utilized for diagnosing meningitis. However, their high cost currently restricts their use primarily to research settings.<sup>29,30</sup>

Staphylococcal species are well-established as common pathogens in PNBM.<sup>31–33</sup> *Acinetobacter* spp., *Klebsiella* spp.,

and other gram-negative bacteria are also recognized etiologic agents.<sup>34,35</sup> Our study findings, which identified *A. baumannii* ( $n = 2$ ), *S. haemolyticus* ( $n = 1$ ), and *K. pneumoniae* ( $n = 1$ ), are consistent with these previously reported common pathogens.

The true incidence of PNBM remains somewhat uncertain due to challenges in definitive diagnosis and the lack of a universally accepted gold standard. Reported incidence rates vary widely, ranging from 0.0007 to 14.8%, influenced by numerous factors.<sup>36,37</sup>

Regarding diagnosis by CSF culture, approximately 70% of patients with suspected bacterial meningitis may yield negative culture results. Thus, adjunct diagnostic methods are essential to complement CSF culture. Delayed diagnosis can have detrimental consequences for patients, potentially leading to delayed initiation of appropriate antibiotic therapy. Conversely, unnecessary administration of antibiotics in suspected cases can result in avoidable side effects and increased health care costs.

Analysis of patient characteristics in this study revealed a near equal distribution of sexes. The most frequently observed underlying condition was ruptured cerebral aneurysm. Most surgical procedures were less than 3 hours in duration.

Based on this study, we propose a diagnostic flowchart-based approach for patients presenting with clinical suspicion of PNBM (→ Fig. 5).

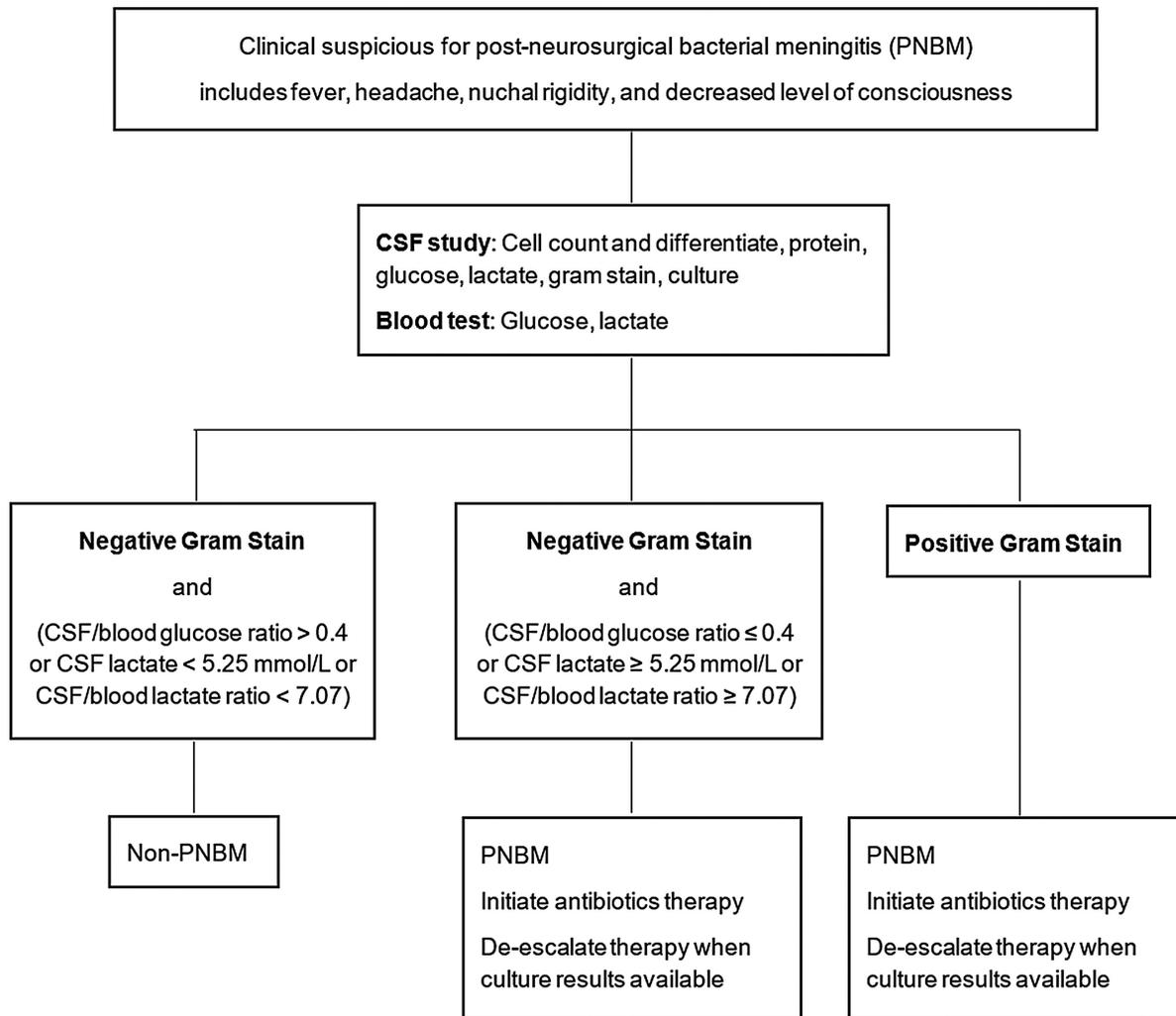
## Limitations

Limitations of this research include the duration of data collection, which ideally should be longer than 2 years to increase the sample size and potentially improve data detail and diagnostic accuracy. Furthermore, data collection from a single center (Faculty of Medicine Vajira Hospital) limits the variability and generalizability of the findings. Collecting data from multiple hospitals would likely increase the sample size and improve the accuracy of calculated parameters.

## Conclusion

In conclusion, our study demonstrates that both CSF lactate and the CSF/blood lactate ratio are valuable in diagnosing PNBM. Based on our findings, a CSF lactate level of 5.25 mmol/L and a CSF/blood lactate ratio of 7.07 serve as relevant diagnostic thresholds. Our results corroborate previous studies on the utility of CSF lactate for diagnosing PNBM, although our findings suggest a potentially higher optimal cut-off value compared to some literature. Furthermore, we found that the CSF/blood lactate ratio is also useful for diagnosis, even in patients who have received antibiotics or have negative CSF cultures, consistent with existing literature. While blood lactate alone was not found to be diagnostic, its measurement is necessary for calculating the CSF/blood lactate ratio, thus retaining its utility as an ancillary test.

Procalcitonin, both CSF and blood levels, and their ratio were not found to be useful for diagnosing PNBM in our study. Therefore, routine measurement of procalcitonin may not be beneficial for this specific diagnosis.



**Fig. 5** Diagnostic approach to post-neurosurgical bacterial meningitis (PNBM).

#### Conflict of Interest

None declared.

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