


# Detection Analysis of Perioperative Plasma and CSF Reveals Risk Biomarkers of Postoperative Delirium of Parkinson's Disease Patients Undergoing Deep Brain Stimulation of the Subthalamic Nuclei

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**Objective:** This study aimed to explore possible biomarkers of postoperative delirium (POD) of Parkinson's disease (PD) patients received deep brain stimulation (DBS) of the subthalamic nuclei.

**Materials and methods:** This nested case control study analyzed perioperative plasma and cerebral spinal fluid (CSF) of patients (n = 40) who developed POD undergone DBS surgery (n = 10) and those who did not (n = 30). Blood sample was collected before surgery and on the first day postoperative, CSF sample was collected at the beginning of the operation. POD was assessed by the Confusion Assessment Method (CAM) twice a day between 7:00 am and 7:00 pm after the surgery until discharge. Plasma and CSF sample from the two groups were analyzed to investigate possible biomarkers for POD in PD patients.

**Results:** There was no difference between POD and Non-POD groups on the concentration of Interleukin 6 and Tumor Necrosis Factor- $\alpha$  in CSF, preoperative plasma and postoperative plasma. There was no difference between POD and Non-POD groups on the concentration of S100 calcium-binding protein  $\beta$  protein (S100 $\beta$ ) and Neurofilament light chain (NFL) in preoperative plasma and postoperative plasma. The concentration of C-reactive protein (CRP), NFL and S100 $\beta$  were significant higher in POD group than non-POD group in CSF. The concentration of CRP was significantly higher in POD group than non-POD group in preoperative plasma and postoperative plasma. CSF concentration of S100 $\beta$  might be a potential biomarker for POD via the receiver operating characteristic curve analysis and the area under the curve value of 0.973.

**Conclusion:** For PD patients received DBS surgery, CSF S100 $\beta$  might be a marker for aiding detection of high-risk patients with delirium. This requires further confirmation in clinical trials.

**Keywords:** Parkinson's disease, deep brain stimulation, cerebrospinal fluid, postoperative delirium, biomarker

## Introduction

Parkinson's disease (PD) is a common neurodegenerative disease,<sup>1</sup> and the advanced PD patients need the Deep brain stimulation of the subthalamic nuclei (STN-DBS) which improves motor and non-motor symptoms,<sup>2-4</sup> and enhance the quality of life.<sup>3-5</sup>

Unfortunately, as one of the most common neuropsychiatric complications following DBS surgery,<sup>6</sup> the incidence of delirium was 22% to 42.6% of patients after DBS surgery.<sup>7,8</sup> Postoperative delirium (POD) is common, serious, costly, under-recognized, and often fatal.<sup>9</sup> For PD patients, POD is an increased risk factor for developing dementia and death.<sup>9</sup>

However, the pathogenesis of POD is unclear.<sup>10</sup> Detecting PD patients at high risk of POD would promote recovery after DBS surgery. Since the pathogenesis of POD is unclear, and clinical symptoms are diverse and fluctuate, the specific biomarkers to predict POD have important implications.<sup>11</sup> The etiology of delirium was multifactorial.<sup>12</sup> Currently, there

is no convincing evidence showed that pharmacologic prevention is effective.<sup>9</sup> Therefore, it is particularly important to screen high-risk patients and intervene in advance. The hypothesized mechanisms of delirium include neurotransmitters,<sup>13</sup> inflammation,<sup>14</sup> physiologic stressors,<sup>15</sup> metabolic derangements,<sup>16</sup> electrolyte disorders,<sup>17</sup> and genetic factors.<sup>18</sup>

This present study was conducted to explore possible biomarkers of POD in PD patients after DBS surgery. The findings might provide valuable scientific clues for the early detection and treatment of POD in PD patients after DBS surgery.

## Methods

### Study Design

This study was performed in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Yuquan Hospital of Tsinghua University (20,190,014). All patients enrolled have signed informed consent. The clinical trial registration number was ChiCTR1900027210.

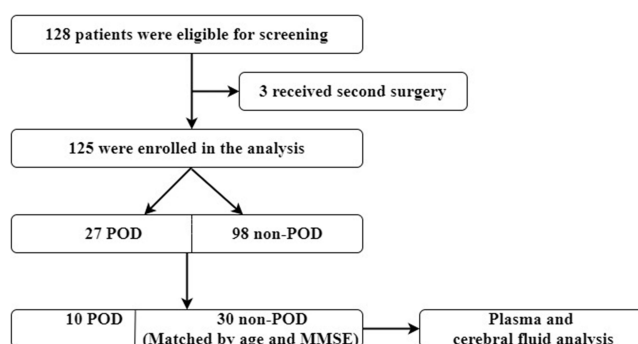
### Study Population

The study was conducted between November 2019 and October 2020 in Yuquan Hospital of Tsinghua University (Beijing, China). The PD patients were diagnosed according to the UK Brain Bank criteria<sup>19</sup> and planned to receive bilateral STN-DBS treatment. Bilateral STN-DBS treatment followed the Movement Disorders Society guidelines.<sup>20</sup> The inclusion and contraindications for DBS surgery were according to the Chinese deep brain stimulation therapy for Parkinson's disease Expert Consensus (Second Edition).<sup>21</sup>

The PD patients (1) were unable to read or had severe visual or auditory deficits, or (2) had a history of alcohol abuse and drug dependence or (3) were unwilling to comply with the study protocol or procedures were excluded.<sup>22</sup> 128 patients participated in this study, 125 participants (27 POD vs 98 Non-POD) completed the study (Figure 1, flow diagram). It was a nested case control study. Considering the cost of testing, we randomly chose 10 cases from the 27 POD patients using the random number table in order to make sure the two groups are comparable, 10 POD patients and the matched 30 non-POD patients by age ( $\pm 2$  years) and MMSE score ( $\pm 2$  points) were chosen to analyze.

### Neuropsychological Testing

Preoperatively, Clinical Dementia Rating score, Instrumental Activity of Daily Living score, MMSE score, Montreal Cognitive Assessment score, Hamilton Anxiety Rating Scale, and Hamilton depression Rating Scale were performed in order to estimate if these patients were suitable for surgery. The Confusion assessment method (CAM)<sup>9</sup> was used to screen POD twice a day between 7:00 am and 7:00 pm after the surgery until discharge.



**Figure 1** Study flow chart. 128 patients were initially screened for the study, and 40 patients were finally included in the analysis.

**Abbreviations:** POD, postoperative delirium; MMSE, Mini-mental state exam.

## Anesthesia and Surgery

A specific team is in charge of the general anesthesia and surgery to avoid interfering factors. The electrocardiograph, non-invasive blood pressure, heart rate (HR), saturation of pulse oximetry, and Bispectral Index (BIS) were monitored during anesthesia and were recorded at fixed intervals of 3 min.

The systemic blood pressure was adjusted to be higher than 90 mm Hg. The anesthesia depth was monitored by the BIS (BIS 40–60).<sup>23</sup>

In this study, the surgery was divided into two parts. Firstly, under the local anesthesia with minimal sedation, the stereotactic DBS electrodes were implanted in the STN. And the place of the electrodes was confirmed by imaging examination. Secondly, the DBS batteries and leads were placed in the sub-clavicular region under general anesthesia.

The same analgesic strategy was used to relieve postoperative pain as following: sufentanil 2 µg/kg + dexmedetomidine 2.3 µg/kg diluted to 100 mL, the background rate was 2 mL/h, the dosage of PCA was 0.5 mL, and the locking time was 15 min.

## Sample Collection

2 mL venous blood was collected through the peripheral vein before the anesthesia. During the DBS surgery, bilateral electrode implantation sites were determined under stereo positioning, and then a U-shaped incision about 5 cm in diameter was made around the implantation site to peel the scalp and expose the skull. A hole is drilled into the skull centered on the site of implantation and the cerebral dura was cut open. At this point, about 2 mL of CSF was taken with a 5 mL syringe by the surgeon.

The Visual Analog Scale (VAS) scores following surgery were recorded. The intensity of postoperative pain was evaluated twice daily at 7:00 am and 7:00 pm with the VAS. The VAS pain scale ranged from 0 to 10 with 0 corresponding to “no pain” and 10 to the “worst possible pain”, the number patients pointed out to indicate the pain intensity.

On the first postoperative day, 2 mL venous blood was taken when routine blood was drawn in the ward for other examinations.

All the samples were centrifuged immediately at 3000 rpm for 10 min at 4°C, and the supernatant was gathered and stored at –80°C.

## Enzyme-Linked Immunosorbent Assay (ELISA)

Levels of Interleukin 6 (IL-6), Tumor Necrosis Factor-α (TNF-α), Neurofilament light chain (NFL), S100 calcium-binding protein β protein (S100β) and C-reactive protein (CRP) in the supernatant of CSF and plasma were determined using commercial ELISA kits according to the manufacturer's instructions. The CRP and IL-6 kits were from Abcam, ab260058 and ab178013, the TNF-α and NFL kits were from International GmbH, BE58351 and 30,112,458, the S100β kits were from R&D Systems, DY1820-5. The optical density (OD) of each well was determined using an ELISA reader at 450 nm.

## Statistical Analysis

The data are described as the mean ± standard deviation (SD), the median, or the number (%). The normality of the variables was tested by the Kolmogorov–Smirnov method. Categorical and continuous variables were analyzed using  $\chi^2$  test and independent-samples *t*-test respectively. The non-normal variables were analyzed by Mann–Whitney *U*-test. Statistical significance was considered at  $p < 0.05$ . SPSS software (version 21.0; IBM Corp., Armonk, NY, USA) was used for data analysis. In order to evaluate the potential biomarkers for POD, the receiver operating characteristic (ROC) curves and the area under the curve (AUC) were calculated.

## Results

### Participant Characteristics

In the present study, 10 CSF samples were collected from POD patients, and 30 matched CSF samples were collected from non-POD patients. There were no differences in the basic characteristics between the two groups including age,

**Table 1** Subject Characteristics

	Non-POD Group (n=30)	POD Group (n=10)	Statistical Test	P-value
<b>Age (years), mean <math>\pm</math> SD</b>	63.70 $\pm$ 4.28	65.70 $\pm$ 4.14	$t = -1.289$	0.205
<b>MMSE score, mean <math>\pm</math> SD</b>	28.27 $\pm$ 1.51	28.10 $\pm$ 0.99	$t = 0.325$	0.747
<b>Male, n (%)</b>	14(46.7)	3 (30.0)	$\chi^2 = 0.853$	0.356
<b>BMI (kg/m<sup>2</sup>), mean <math>\pm</math> SD</b>	24.72 $\pm$ 5.13	22.66 $\pm$ 3.86	$t = 1.163$	0.252
<b>ASA class, n (%)</b>				
<b>I</b>	8(26.7)	1 (10.0)	$\chi^2 = 2.156$	0.340
<b>II</b>	20(66.7)	9 (90.0)		
<b>III</b>	2(6.7)	0 (0)		
<b>Length of anesthesia (min), mean <math>\pm</math> SD</b>	97.83 $\pm$ 27.03	99.90 $\pm$ 27.65	$t = -0.028$	0.836
<b>Length of surgery (min), mean <math>\pm</math> SD</b>	69.80 $\pm$ 24.78	74.50 $\pm$ 25.76	$t = -0.515$	0.610
<b>Postoperative VAS score, mean <math>\pm</math> SD</b>	3.7 $\pm$ 0.84	3.2 $\pm$ 0.63	$t = 1.727$	0.092
<b>Intraoperative infusion volume(mL), mean <math>\pm</math> SD</b>	1596.67 $\pm$ 396.09	1370.00 $\pm$ 505.64	$t = 1.462$	0.152
<b>Estimated blood loss(mL), mean <math>\pm</math> SD</b>	78.33 $\pm$ 24.51	77.00 $\pm$ 28.69	$t = 0.143$	0.887
<b>Intraoperative urinary volume(mL), mean <math>\pm</math> SD</b>	471.67 $\pm$ 239.86	495.00 $\pm$ 256.53	$t = -0.262$	0.795
<b>Length of stay in hospital after surgery, (d)</b>	9.03 $\pm$ 1.54	12.5 $\pm$ 2.7	$t = -5.543$	0.000

**Abbreviations:** MMSE, Mini-Mental State Examination; BMI, body mass index; ASA, American Society of Anesthesiologists; VAS, Visual Analogue Scale; kg, kilogram; m, meter; min, minute; mL, milliliter; SD, standard deviation.

MMSE score, gender, body mass index, American Society of Anesthesiologists (ASA) physical class, length of anesthesia and surgery, postoperative VAS scores, intraoperative infusion volume, estimated blood loss and intraoperative urinary volume. The length of stay in the hospital was significantly longer in the POD group than in the non-POD group. There were no deaths in either group (Table 1).

## Comparison of CSF Levels of Cytokines Between POD and Non-POD Patients

There was no difference between POD and Non-POD groups on the concentration of IL-6 and TNF- $\alpha$  in CSF at the beginning of surgery (Figure 2A). However, the concentration of S100 $\beta$ , NFL and CRP were significantly higher in POD group than non-POD group at the beginning of surgery (Figure 2B).

## Comparison of Preoperative Plasma Levels of Cytokines Between POD and Non-POD Patients

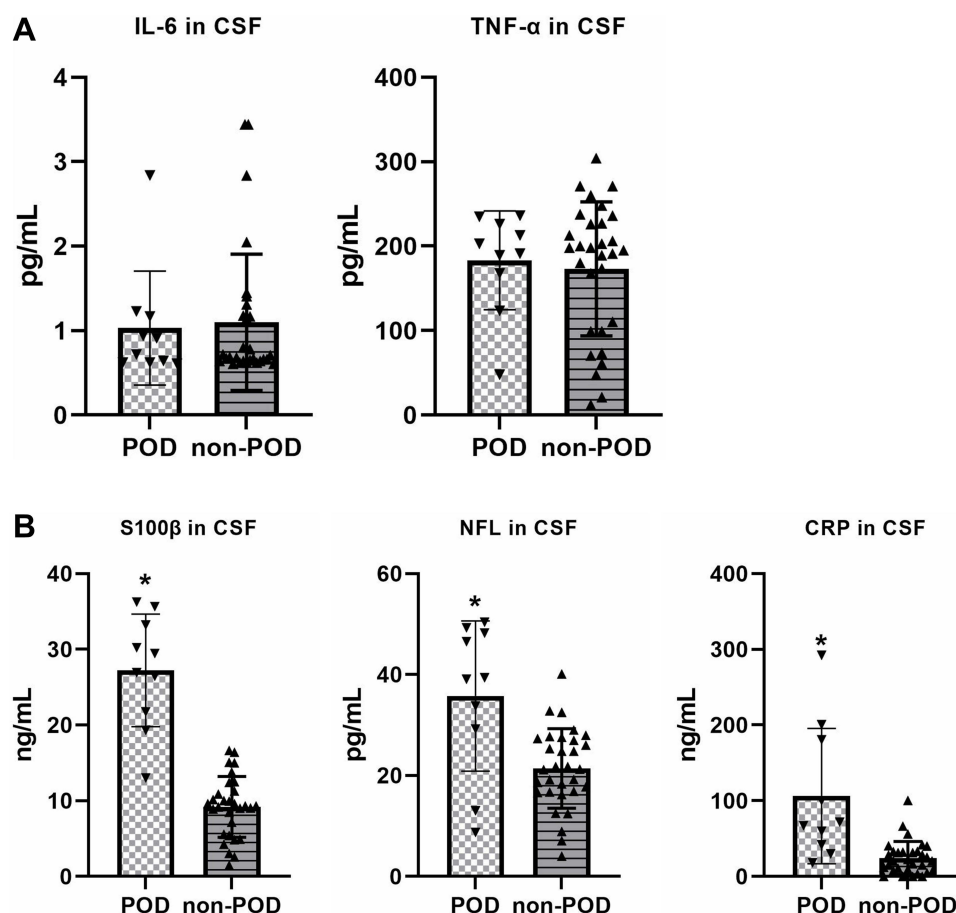
There was no difference between POD and Non-POD groups on the concentration of IL-6, TNF- $\alpha$ , S100 $\beta$  and NFL in preoperative plasma. However, the concentration of CRP was significantly higher in POD group than non-POD group (Figure 3A and B).

## Comparison of Postoperative Plasma Levels of Cytokines Between POD and Non-POD Patients

There was no difference between POD and Non-POD groups on the concentration of IL-6, TNF- $\alpha$ , S100 $\beta$  and NFL in postoperative plasma. However, the concentration of CRP was significantly higher in POD group than non-POD group (Figure 4A and B).

## Univariate and Multivariate Logistic Regressions

The logistic regressions were performed to identify the potential risk factors of POD. All the variables were screened using the univariate regression and the variables with  $P < 0.05$  were selected for multivariate logistic regression. Among the variables screened, the S100 $\beta$  concentrations in CSF might be an independent influence factor of POD (Table 2).



**Figure 2 (A)** There was no difference between POD and Non-POD groups on the concentration of IL-6 and TNF- $\alpha$  in cerebral spinal fluid at the beginning of surgery; **(B)** the concentration of CRP, NFL and S100 $\beta$  were significant higher in POD group than non-POD group at the beginning of surgery. \* $p < 0.05$  compared with non-POD group. **Abbreviations:** POD, postoperative delirium; CSF, cerebral spinal fluid.

## Diagnostic Analysis of Indicators for the Prediction of POD

The total area under the curve AUC, cut-off, sensitivity, specificity, and Youden index of independent influence factors of POD are shown in Table 3.

The receiver operating characteristic (ROC) curve was used to determine the optimal cut-off score for the diagnosis of POD. The optimal score was calculated according to the Youden index (maximum of [sensitivity + specificity-1]).<sup>24</sup>

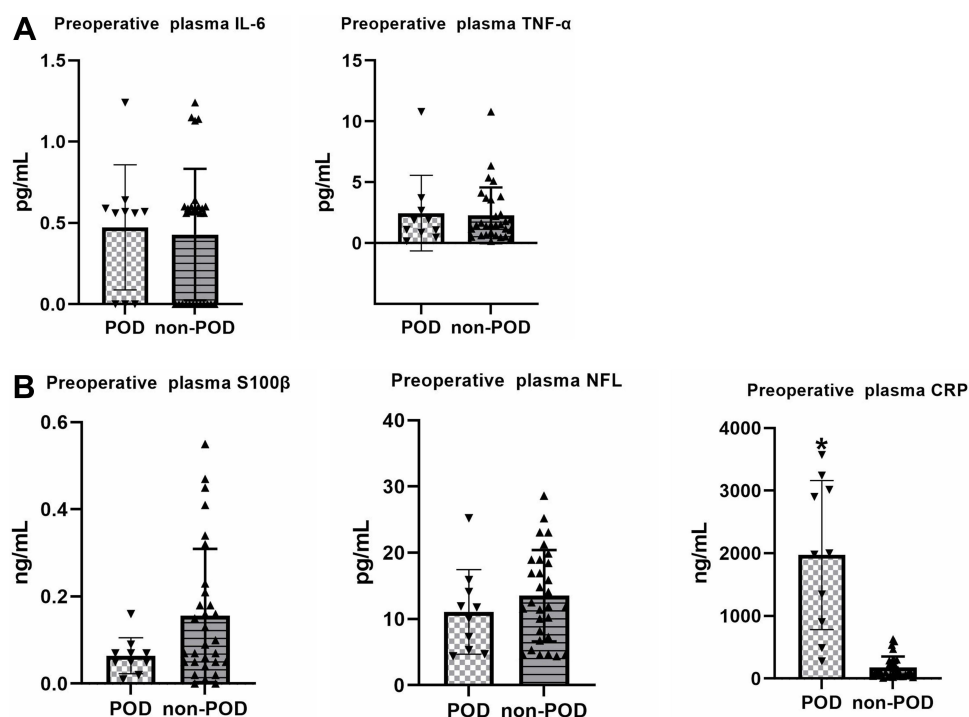
In the present study, 17.982 as the optimal cut-off score of S100 $\beta$  concentrations in CSF-associated with the POD. The sensitivity and specificity were 90.0% and 96.7%, respectively. The AUC was 0.973 (95% CI: 0.928–1.000,  $P < 0.05$ ) (Table 3, Figure 5).

## Discussion

PD is a common neurodegenerative disease in the elders, and the STN-DBS treatment is a standard option for advanced PD patients.<sup>19</sup> However, POD is common after DBS surgery and associated with worsened clinical outcomes, increased costs and mortality.<sup>9</sup>

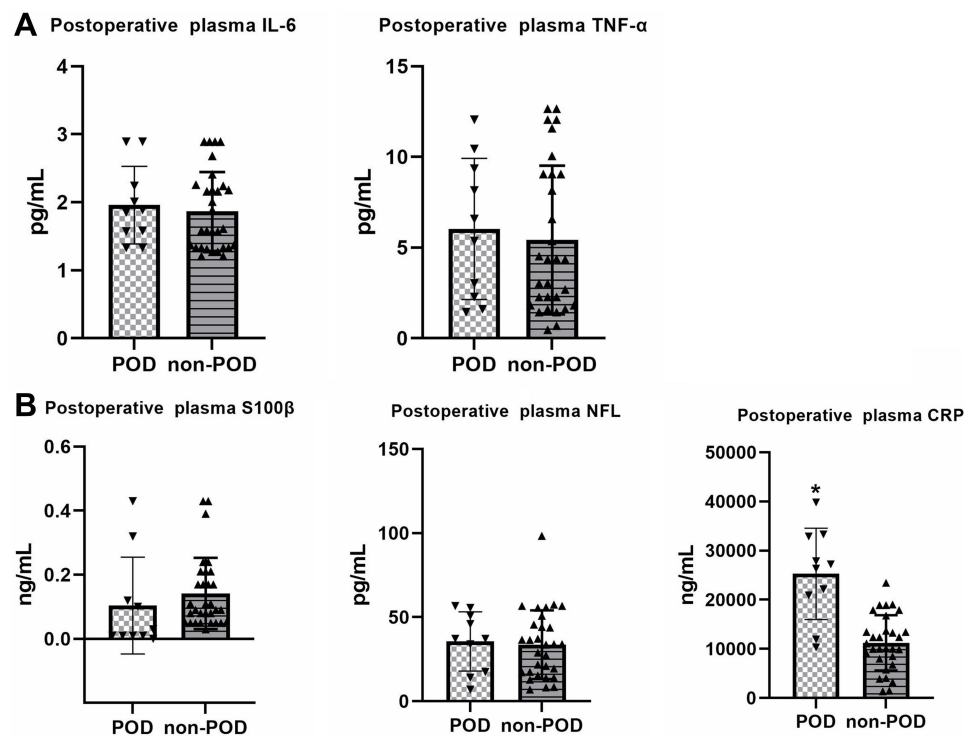
There was a link between inflammation markers and delirium.<sup>25,26</sup> Elevated inflammatory biomarkers have been indicated as predictors of delirium in the general population<sup>27</sup> including one of the most commonly examined markers of systemic inflammation CRP,<sup>28,29</sup> TNF- $\alpha$ <sup>30</sup> and IL-6.<sup>31,32</sup>

Sarinnapha et al's study showed high preoperative and postoperative day 2 plasma CRP were independently associated with delirium incidence, duration, and feature severity. CRP might be useful to identify individuals who are at risk of developing delirium.<sup>33</sup> Slor, Chantal J also reported that delirium is associated with an increased systemic



**Figure 3** (A) There was no difference between POD and Non-POD groups on the concentration of IL-6 and TNF- $\alpha$  in preoperative plasma; (B) there was no difference between POD and Non-POD groups on the concentration of S100 $\beta$  and NFL in preoperative plasma. The concentration of CRP was significant higher in POD group than non-POD group in preoperative plasma. \* $p < 0.05$  compared with non-POD group.

**Abbreviations:** POD, postoperative delirium; CSF, cerebral spinal fluid.



**Figure 4** (A) There was no difference between POD and Non-POD groups on the concentration of IL-6 and TNF- $\alpha$  in postoperative plasma; (B) there was no difference between POD and Non-POD groups on the concentration of S100 $\beta$  and NFL in postoperative plasma. The concentration of CRP was significant higher in POD group than non-POD group in postoperative plasma. \* $p < 0.05$  compared with non-POD group.

**Abbreviations:** POD, postoperative delirium; CSF, cerebral spinal fluid.

**Table 2** Univariate and Multivariate Logistic Regressions

	Predictor Variable	Univariate Analysis		Multivariate Analysis	
		OR (95% CI)	P-value	OR (95% CI)	P-value
CSF	CRP, (ng/mL)	1.01(1.00–1.03)	0.035	1.55(1.08–2.22)	0.016
	NFL, (pg/mL)	1.23(1.08–1.41)	0.003		
	S100 $\beta$ , (ng/mL)	1.41(1.13–1.77)	0.002		
Preoperative Plasma	CRP, (ng/mL)	1.01(1.00–1.01)	0.024		
Postoperative plasma	CRP, (ng/mL)	1.00(1.00–1.00)	0.002		

**Abbreviations:** CSF, cerebral spinal fluid; CRP, C-reactive protein; NFL, neurofilament; S100 $\beta$ , S100 calcium-binding protein  $\beta$  protein.

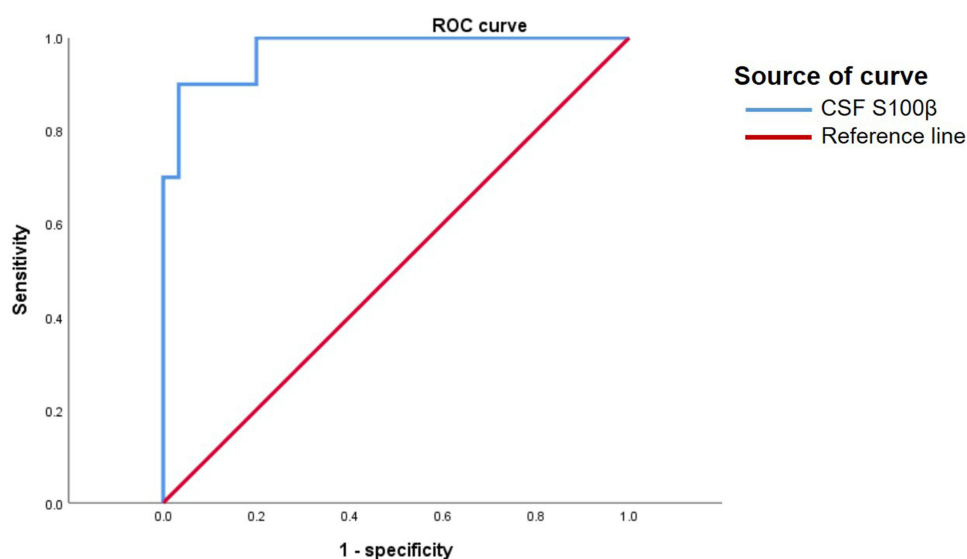
**Table 3** Diagnostic Analysis of Indicators for the Prediction of POD

Variable	AUC	P-value	95% CI	
			Low	High
S100 $\beta$	0.973	0.000	0.928	1.000
Variable	Cut-off	Sensitivity	Specificity	Youden Index
S100 $\beta$	17.982	90.0%	96.7%	0.867

**Abbreviation:** AUC, area under the curve.

inflammatory response, and suggest that CRP plays a role in the underlying pathological pathway of POD.<sup>34</sup> Dimitrios Adamis reported that high levels of CRP are associated with delirium in acute orthopaedic and elective abdominal operations.<sup>35</sup> However, Mehmet Alper ÇINAR1 and et al reported that there was no difference between POD and non-POD group on the blood level of CRP.<sup>28</sup> Therefore, CRP was also selected as a detection indicator in our study. We also noted that the concentration of CRP was significantly higher in POD group than non-POD group in CSF, preoperative plasma and postoperative plasma.

TNF- $\alpha$  and IL-6 were associated with memory and learning.<sup>36,37</sup> High levels of IL-6 seem a consistent predictor for delirium in surgical samples.<sup>35</sup> Kazmierski et al reported an elevation of TNF- $\alpha$  levels in the postoperative period in coronary artery bypass graft (CABG) patients with delirium.<sup>30</sup> Ganna Androsova1 mentioned IL-6 and TNF- $\alpha$  could be

**Figure 5** ROC analysis showed the probability of the POD increases with the rise of concentration of S100 $\beta$  in cerebral spinal fluid.



biomarkers in predicting delirium.<sup>32</sup> Plaschke K reported that early POD after cardiac surgery is associated with increased IL-6.<sup>31</sup> However, in the present study, there was no difference between POD and Non-POD groups on the concentration of IL-6 and TNF- $\alpha$  in CSF, preoperative plasma and postoperative plasma.

NFL protein is an intermediate filament in the cytoplasm of neurons, which is mainly expressed in the dendrites and axons of neurons, and plays an important role in the construction of cytoskeleton to maintain the structural stability of neurons.<sup>38,39</sup> At present, the increased level of NFL in CSF and blood has been detected in Alzheimer's disease, amyotrophic lateral sclerosis (ALS) and brain injury, and it is believed that the increased concentration of NFL is correlated with the progression of the disease.<sup>40,41</sup> In the study of Linda P, patients with higher level of CSF neurofilament light were accompanied with worse memory, attentional and executive functioning.<sup>42</sup> Saller mentioned in their study that NFL might be of benefit to identify high risk patients for delirium.<sup>43</sup> In the present study, the concentration of NFL was significantly higher in POD group than non-POD group.

S100 $\beta$  is a member of the calcium-regulated protein S100 family and is characterized by two calcium-binding sites with EF-hand conformations.<sup>44</sup> It is mainly expressed by astrocytes and found both intra- and extra-cellularly in brain tissue.<sup>45</sup> Because of functional impairment of membrane integrity and/or increased blood-brain barrier permeability, it is usually elevated in blood and CSF after nervous system injury.<sup>46</sup> Therefore, it could have a clinical role in the assessment of brain injury and could be a marker of brain damage used in various diseases.<sup>47</sup>

S100 $\beta$  has also attracted attention in the field of biomarkers of delirium.<sup>48–51</sup> Layth Al Tmimi et al reported that serum-levels of S100 $\beta$  measured on the first postoperative day in POD patients were significantly higher than non-POD patients.<sup>52</sup> S100 $\beta$  was proposed by Khan et al as a promising and specific marker for delirium.<sup>53</sup>

In the present study, it was also showed that the S100 $\beta$  level in CSF was indicated to be independent influence factors of POD. There was no difference between POD and Non-POD groups on the concentration of S100 $\beta$  in preoperative plasma and postoperative plasma. However, the concentration of S100 $\beta$  was significant higher in POD group than non-POD group in CSF. And among the variables screened, S100 $\beta$  concentrations in CSF was displayed to be independent risk factors of POD.

One possible mechanism for the higher level of S100 $\beta$  after delirium is active stimulation of astrocytes or increased permeability of the blood-brain barrier.<sup>54–56</sup> The neurobehavioral and cognitive characteristic of delirium associated by the change in synaptic transmission, neural excitability, and cerebral blood flow resulted by high CSF S100 $\beta$ .<sup>57</sup> S100 $\beta$  has been considered as a putative biomarker of CNS damage, and increased CSF and serum levels of S100 $\beta$  are associated with the adverse CNS outcomes, especially delirium.<sup>58–60</sup> Another hypothesis could be activation of the nuclear factor  $\kappa$ B signal pathways and lead to up-regulation of proinflammatory mediators.<sup>61</sup> S100 $\beta$  may play a role in BBB disruption and contribute to delirium.<sup>54</sup> Finally, CSF could accurately reflect biochemical changes in the central nervous system.<sup>11</sup> Compared with plasma, CSF S100 $\beta$  level was more significant in predicting the POD.<sup>42</sup>

For PD patients undergoing DBS surgery, it is necessary to cut the dural during the surgery. Collecting CSF at this time is simple to do and without additional damage. So, the CSF S100 $\beta$  might be a marker for aiding early diagnosis of delirium after DBS surgery for PD patients.

We also did a number of measures to reduce the possible risk of POD just as following. Deep anesthesia might associate with delirium.<sup>23</sup> So, in the present study, BIS value was maintained within 40 to 60 in order to avoid episodes of deep anesthesia. POD is also associated with reduction in the intraoperative cerebral blood flow (CBF).<sup>62</sup> Therefore, the systemic blood pressure was kept higher than 90 mm Hg to ensure adequate CBF in the present study. Some studies showed severe pain may induce cognitive decline after surgery,<sup>63</sup> so, all the patients in this study received effective pain control.

## Limitations

Although CSF S100 $\beta$  could be regarded as a potential biomarker of delirium in this study, limitations should be noticed. First, we aimed to recruit the maximum number of patients available and have not performed power calculations. Second, it was a monocentric study as only a few hospitals currently perform the DBS surgery. Third, there were only 10 POD patients and 30 non-POD patients in the biomarker analysis. Further analysis needs to be performed in future studies.



## Conclusion

In this exploratory study of PD patients received DBS surgery, CSF S100 $\beta$  might be a marker for aiding detect high-risk patients of delirium. This requires further confirmation in clinical trials.

## Data Sharing Statement

All the authors intend to share individual deidentified participant data including all the raw data. Immediately after the article is published, all the data could be shared by email to the corresponding author.

## Funding

The present study was supported by the National Natural Science Foundation of China (81801070).

## Disclosure

The authors report no conflicts of interest in this work.

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