ORIGINAL RESEARCH

Cytokines and chemokines expression in serum of patients with neuromyelitis optica

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Objective: To study the differences in immunopathogenesis based on chemokine profile in neuromyelitis optica patients positive for AQP4 antibodies or MOG antibodies.

Patients and methods: We measured 52 cytokines/chemokines using ELISA in 59 serum samples, which were divided into three groups according to CBA results: HCs (n=16), AQP4+ (n=20) and MOG+ (n=23). The regression equation ($R^2 > 0.98$) of the standard curve was calculated according to the standard concentration and the corresponding A value. And then the corresponding sample concentration was calculated according to the A value of the sample.

Results: Eleven of 52 measured serum cytokine/chemokines (CCL22/MDC, CCL13/MCP-4, CCL21/6Ckine, CCL27/CTACK, CCL8/MCP-2, CXCL14/BRAK, Contactin-1, Kallilrein 6/Neurosin, Midkine, VCAM-1 and Fas) were significantly different between MOG+ group and controls. Ten of 52 measured serum cytokine/chemokines (CCL1/I-309, CCL22/MDC, CCL28, CCL17/TARC, CCL27/CTACK, CXCL2/GRO beta, Contactin-1, Midkine, Chemerin and Synuclein-alpha) were significantly different between AQP4+ group and controls. There was no difference between serum AQP4+ and MOG+ groups for CC chemokines. All measured chemokines CXC except CXCL6/GCP-2 showed no significant differences in serum AQP4+ group compared to MOG+ group. However, there was significant difference between serum AQP4+ and MOG+ groups for C5/C5a and Midkine. C5/C5a and Midkine were significantly higher in AQP4+ group compared to MOG+ group ($P < 0.05$).

Conclusion: Our findings suggest that the differences of mean concentration in CXCL6/GCP-2, Midkine and C5/C5a probably reveal different immunologic mechanism between AQP4+ NMO and MOG+ NMO. This cytokine/chemokine profiling provides new insight into NMO pathogenesis associated with MOG antibody seropositivity and provides guidance to monitor inflammation and response to treatment in a way.

Keywords: NMO, AQP4 antibodies, MOG antibodies, cytokines, chemokines

Introduction

Demyelinating disease of the CNS is closely related to optica neuritis (ON), an inflammatory demyelinating disease involving optic nerve and causing axonal damage.[1,2] ON is characterized by sudden monocular visual loss and eye pain in young adults, more commonly in women. ON is regarded as a common initial manifestation of MS.[3] In addition, a small number of ON patients with positive autoimmunity antibody like ANAs probably undergo optic neuropathy, which was considered as inflammatory optic neuropathy or autoimmune optic neuropathy.[4] In western countries, ON is mostly defined as IDON, which is closely related to MS.[5] And NMO, a severe autoimmune and inflammatory disease of the CNS, is characterized by recurrent ON and LETM.[6] NMO is one of the most common causes of non-traumatic disability in middle-aged and youth, the incidence of which is second only to MS. In 2004, a specific antibody NMO-immunoglobulin G

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(IgG) was found in the serum of NMO patients and the target antigen of NMO-IgG is AQP4, the detection of NMO-IgG/AQP4 antibodies in NMO serum has high sensitivity and specificity, up to 73% and 91%, respectively.[7] According to the 2006 revised diagnostic criteria for NMO, seropositivity for IgG antibodies that bind to AQP4 on astrocytes is one of three supporting conditions, thus there is no doubt that AQP4-Ab is of great importance in the diagnosis of NMO.

The discovery of an NMO-specific auto-antibody to the AQP4 water channel has improved knowledge of NMO pathogenesis. However, through the clinical practice, it is found that negative AQP4 Ab was presented in about 10%–20% NMO patients.[7,8] The AQP4 Ab-negative NMO patients may have a completely different pathogenesis from the AQP4 Ab positive NMO. In 2011, it was first reported that auto-antibodies against oligodendrocyte glycoprotein are present in the NMO patients, namely MOG, which is often detected in the serum of AQP4-negative NMO patients.[9] MOG is a myelin antigen located at the outer surface of the CNS myelin sheath and is a target for autoimmune responses that results in CNS inflammation and demyelination. There is emerging evidence that MOG antibodies are pathogenic in human demyelinating diseases. In vitro experiments have shown that patient serum containing MOG antibodies can induce complement, natural killer cell and antibody dependent cell-mediated toxicity, and disrupt oligodendrocyte cytoskeleton.[9–13] NMO associated with AQP-4 antibodies is an astrocytopathy, and there are a large number of studies demonstrating a complex immunopathology involving B cells, eosinophils, neutrophils and Th17 cell mechanisms.[14–16] By contrast, other than autoantibody-associated mechanisms, there is limited information available on the immune-pathogenesis of MOG antibody-mediated inflammation. Likewise, although the presence of different CSF cytokines and chemokines has previously been investigated in NMO,[17] Uzawa et al proposed that NMO patients have elevated CSF cyto/chemokines associated with Th17 (IL-6, IL-8 and G-CSF), Th2 (IL-1ra, IL-10 and IL-13) and B cell axes (CXCL13, BAFF, APRIL and IL-21), which contrasts with MS which is primarily a Th1-dominant disease.[17] Previous study also points that increased concentrations of BAFF, IL-17, IL-6 and CXCL13 have been proposed to be key factors that induce the formation of NMO lesions, mainly by promoting the infiltration of neutrophils or plasma cells,[17–21] and these molecules have been shown to correlate with disease severity and expanded disability status scale score.[22,23] However, serum cytokine studies in MOG-associated demyelination are lacking.

In view of emerging evidence of pathogenicity, we hypothesize that AQP4 Ab POS NMO has different pathogenicity of MOG Ab POS NMO. In this study, we investigated and analyzed a broad array of serum cytokine/chemokine levels in AQP4+ group and MOG+ group and their association, to identify whether some cytokine/chemokine can be biomarkers to identify the immunologic mechanism of MOG+ NMO.

Patients and methods
Subjects
We studied 43 patients with the following criteria were selected: 1) initial diagnosis of NMO. All patients fulfilled the 2006 diagnostic criteria for NMO, revised by Wingerchuk et al, 2) in the acute phase with the first attack and 3) participants had not been treated with large dose of corticosteroid and not used immunosuppressive agents and never received immunomodulatory treatments.

Ethics statment
This work was approved by the People's Liberation Army General Hospital Research Ethics Committee (No S2015-029-01) and was conducted according to the Declaration of Helsinki in its latest applicable version.

Plasma sample analysis
Patients donated 10 mL of blood between January 2016 and January 2018 and serum was collected in heparinized tubes. Blood was diluted 1:1 with 0.9% NaCl and overlaid onto lymphocytes separation medium (PAA Laboratories GmbH, les Mureaux, France). After centrifugation, the plasma was collected and stored at −80°C.

CBA for detection of AQP4 and MOG IgG status
HEK293T cells, polyethylenimine transfected with human M23-AQP4 and FL-MOG were used as the substrate for live CBAs, which were performed as described elsewhere.[7–9] Patient sera were tested at 1:100 dilution. The Alexa Fluor 488 goat anti-human IgG (H + L) (cat. no ab201540; Abcam, Cambridge, UK) was used at 1:250 dilution. The AQP4 and MOG IgG status of NMO patients was then determined; AQP4 and MOG are transmembrane glycoproteins, and NMO associated IgGs are marked by green fluorescence in the cell membrane. A positive and negative control was set up in the experiment as follows: rabbit anti-human MOG (1 µg/mL; cat. no M0695) and AQP4 (1 µg/mL) antibody (cat. no G9626), both Sigma-Aldrich; Merck KGaA, were added to the serum obtained from a healthy individual as the positive control at room temperature overnight, while serum obtained from a healthy individual was used as a negative control.

NMO grouping

AQP4 antibody and MOG IgG in patients meeting the diagnostic criteria for NMO were detected via the CBA at the General Hospital of the People's Liberation Army (PLAGH). According to the CBA results, serum samples were divided into MOG IgG (+) AQP4 IgG (−) group (MOG+ group) and MOG IgG (−) AQP4 IgG (+) group (AQP4 IgG+ group). None of the patients were positive and negative for both MOG-Abs and AQP4-Abs. A total of 20 patients with AQP4 Ab POS (1 male, 19 females; age mean ± SEM: 39.65±3.105; range =13–62) and 23 patients with MOG Ab POS (11 females, 12 males; age mean ± SEM: 32.18±2.927; range =10–62) demyelination were included. And 16 HCs were also selected in the control group. Clinical characteristics in AQP4 Ab POS and MOG Ab POS demyelination syndromes are shown in Table 1. All serum samples were collected during routine diagnostic work-up, prior to commencing treatment, and samples were frozen and stored at −80°C until analysis for cytokines and chemokines. As part of the ethically approved protocol, we have got written consent from all involved patients and participants for this study. And this study was also approved by the People's Liberation Army General Hospital Research Ethics Committee (No S2015-029-01) and was conducted according to the Declaration of Helsinki in its latest applicable version.

Cytokine and chemokine assay

Fifty-two cytokines (IL-28A, IL-17E/IL-25, IL-16, IL-31, IL-21), a series of chemokines (CCL1/I-309, CCL2/MCP-1, CCL24/Eotaxin-2, CCL22/MDC, CCL4/MIP-1 beta, CCL13/MCP-4, CCL13/MIP-3 beta, CCL28, CCL26/Eotaxin-3, CCL25/TECK, CCL11/Eotaxin, CCL17/TARC, CCL21/6Ckine, CCL27/CTACK, CCL20/MIP-3, CCL8/MCP-2, CXCL10/IP-10, CXCL2/GRO beta, CXCL13/BLC/BCA-1, CXCL1/GRO alpha, CXCL5/ENA-78, CXCL16, CXCL14/BRAK, CXCL6/GCP-2, CX3CL/Fractalkine, CXCL9/MIG and CXCL11/ITAC-1) and others (C5/C5a, APP, Granzyme A, Contactin-1, Kallilrein 6/Neurosin, Granzyme B, Synuclein-alpha, Midkine, Chemerin, BMP-9, PARK5/UCH-L1, GDNF, NCAM-1/CD56, S100B, Fas Ligand, LT-alpha/TNF-beta, Enolase 2/NSE, VCAM-1,

ICAM-1 and Fas) were measured by means of ELISA. The regression equation of the standard curve ($R^2>0.98$) was calculated according to the standard concentration and the corresponding A value. And the corresponding sample concentration was calculated according to the A value of the sample.

Statistical analysis

Statistical analysis was performed using R statistical programme and graphs were composed using Graph Pad Prism software version 5.0. The serum cytokine/chemokine data were analyzed to check for a normal distribution. As data did not show Gaussian distribution, statistical analyses of cytokine/chemokine levels were performed using Kruskal–Wallis test for multiple groups and Mann–Whitney test for two groups and two-tailed P-value was calculated. This study was largely exploratory with an intention to study the immunopathological mechanisms based on serum cytokines/chemokines. The P-values from these analyses should be viewed as a measure of the strength of evidence for each association. To reduce type I errors, Bonferroni correction had been applied on the computed P-values. In the correlation analysis, P-values <0.05 were considered to indicate statistical significance.

Results

Comparison of serum cytokine/chemokine levels between AQP4+ group, MOG+ NMO group and controls

Table 2 presents the mean concentration for all serum cytokine/chemokines and statistical comparisons, presented according to CC, CXC, interleukins and other cytokines/chemokines.

Eleven of 52 measured serum cytokine/chemokines (CCL22/MDC, CCL13/MCP-4, CCL21/6Ckine, CCL27/CTACK, CCL8/MCP-2, CXCL14/BRAK, Contactin-1, Kallilrein 6/Neurosin, Midkine, VCAM-1 and Fas) were significantly different between MOG+ group and controls.

Ten of 52 measured serum cytokine/chemokines (CCL1/I-309, CCL22/MDC, CCL28, CCL17/TARC, CCL27/CTACK, CXCL2/GRO beta, Contactin-1, Midkine,

Table 1 Clinical characteristics in AQP4 Ab POS and MOG Ab POS demyelination syndromes

Clinical characteristics	Group		
	AQP4+ (n=20)	MOG+ (n=23)	HCs
Clinical syndrome (n)	TM (5), ON (6), TM+ ON (9)	TM (4), ON (7), TM+ ON (12)	N/A
Age, mean ± SEM (range)	39.65±3.105 (13–62)	32.18±2.927 (10–62)	30.23±2.35 (12–59)
Duration of follow up, mean (SD)	20.8 (19.1)	22.8 (18.8)	N/A

Abbreviations: HCs, healthy controls; N/A, not applicable; ON, optica neuritis; TM, transverse myelitis.

Table 2 Serum cytokine/chemokine concentrations in AQP4+, MOG+ group and controls according to chemokines CC, CXC, IL and other subsets

Cytokines/chemokines (pg/mL)	AQP4+	MOG+	HC	AQP4+ vs control	MOG+ vs control	MOG+ vs AQP4+
	Mean ± SEM			P-values		
Chemokines CC						
CCL1-/I-309	1.394±0.05254	1.466±0.0672	1.675±0.05909	0.0033*	0.1002	1.2297
CCL2/MCP-1	274.1±35.74	240.5±31.26	266.4±22.9	0.4281	0.2469	0.273
CCL24/Eotaxin-2	1,250±140.2	1,165±143.3	1,163±129.7	1.9755	2.9817	2.0226
CCL22/MDC	273.8±52.94	329.4±63.84	652.1±35	<0.0001***	0.0012**	1.542
CCL4/MIP-1 beta	618.4±102.7	818.3±115.8	578.8±55.91	1.3923	0.6897	1.4229
CCL13/MCP-4	66.86±6.861	62.66±6.785	91.92±9.05	0.0933	0.0363*	2.0007
CCL13/MIP-3 beta	62.3±14.41	45.01±7.667	73.46±10.5	1.6629	0.0933	0.8349
CCL28	30.51±0.3193	32.64±1.077	34.02±1.51	0.0495*	1.3431	0.2466
CCL26/Eotaxin-3	7.936±0.4584	7.334±0.1665	14.02±5.538	0.6852	0.4623	0.6024
CCL25/TECK	44.89±6.384	38.12±5.56	54.16±10.5	1.4166	0.5874	1.2885
CCL11/Eotaxin	124.1±23.59	94.9±10.66	112.5±18.36	2.1372	1.1466	0.7365
CCL17/TARC	211.4±26	323.9±46.25	436.1±55.1	0.0012**	0.3834	0.1449
CCL21/6Ckine	120.4±12.49	94.59±5.947	192.5±28.96	0.0579	0.0012**	0.1755
CCL27/CTACK	288.4±22.82	322.8±19.33	401.1±22.92	0.0045**	0.0393*	0.7617
CCL20/MIP-3	114.5±42.05	52.11±10.09	51.37±32.05	0.7806	2.9397	0.3966
CCL8/MCP-2	68.03±14.95	50.15±7.198	80.73±7.716	1.4643	0.0219*	0.8031
Chemokines CXC						
CXCL10/IP-10	24.15±2.972	36.3±6.327	25.58±4.24	2.3334	0.6282	0.3162
CXCL2/GRO beta	357.3±42.88	497.8±54.14	593.3±60.18	0.0072**	0.7551	0.1596
CXCL13/BLC/BCA-1	72.28±13.21	38.35±5.383	42.25±7.561	1.0983	0.63	0.0699
CXCL1/GRO alpha	133.5±18.15	130.3±26.3	307.6±139.3	0.5259	0.4413	2.7672
CXCL5/ENA-78	601.3±71.65	738.1±104.6	3,268±2,164	0.5283	0.5037	0.9048
CXCL16	1,205±72.84	1,310±66.91	1,233±83	2.4129	1.4028	0.8787
CXCL14/BRAK	347±36.05	265.2±29	382.9±20.22	1.2705	0.0132*	0.2445
CXCL6/GCP-2	124.1±12.79	186.1±11.44	174.5±24.41	0.1923	1.9239	0.0024**
CX3CL/Fractalkine	1,136±88.44	1,070±97.87	957.6±98.91	0.5661	1.3107	1.8846
CXCL9/MIG	302.9±24.58	486.7±136.7	326.5±23.16	1.4931	1.0191	0.669
CXCL11/ITAC-1	29.51±4.297	31.99±5.102	36.15±12.28	1.7469	2.1855	2.1495
IL						
IL-28A	44.1±1.11	43.95±1.337	43.37±1.569	1.437	2.319	0.555
IL-17E/IL-25	129.7±8.393	147.1±31.24	137.2±17.77	2.061	2.4255	1.8519
IL-16	235±29.14	245±45.11	238.6±58.1	2.8602	2.7894	2.5719
IL-31	29.42±4.073	29.52±4.965	45.03±7.67	0.198	0.2511	2.9634
IL-21	9.821±0.3029	10.03±0.1326	10.55±0.8198	1.1193	1.3782	1.5594
Others						
C5/C5a	1,072±131.3	632.2±112.5	635±137	0.0867	2.9625	0.0432*
APP	61,616±10,139	49,622±4,632	52,639±4,968	1.464	2.1594	0.8022
Granzyme A	22.58±1.977	22.33±2.292	26.24±1.443	0.4869	0.6033	2.8026
Contactin-1	4,267±375.7	4,061±371.5	6,526±368.3	0.0006***	<0.0001***	2.1021
Kallilrein 6/Neurosin	38,386±34,672	3,319±200.4	4,325±344.1	1.1613	0.0318*	0.8508
Granzyme B	11.35±1.019	10.23±0.8557	23.93±6.843	0.1512	0.0684	1.206

(*Continued*)

Table 2 (*Continued*)

Cytokines/chemokines (pg/mL)	AQP4+	MOG+	HC	AQP4+ vs control	MOG+ vs control	MOG+ vs AQP4+
Synuclein-alpha	341.3±13.97	410.7±25.5	487.6±47.41	0.0078**	0.3951	0.0816
Midkine	88.33±5.206	71.84±3.757	119.6±12.2	0.0477*	0.0003***	0.0372*
Chemerin	2,089±226.7	2,463±441.4	3,787±581.2	0.0201*	0.2187	1.4082
BMP-9	110.3±17.13	83.63±16.2	121.3±20.32	2.0442	0.4578	0.7932
PARK5/UCH-L1	795.3±98.34	622.3±51.76	1,019±240.8	1.0788	0.1965	0.342
GDNF	1.907±0.08243	1.695±0.09299	1.852±0.08981	1.965	0.7503	0.2988
NCAM-1/CD56	150,755±14,850	133,418±12,235	154,298±13,246	2.5896	0.7893	1.1061
S100B	182.1±48.02	111.9±30.72	85.81±18.41	0.2883	1.5534	0.6402
Fas ligand	30.99±3.299	35.31±2.664	37.66±3.501	0.5322	1.7709	0.9297
LT-alpha/TNF-beta	1.606±0.09898	1.467±0.06811	3.302±1.736	0.8454	0.633	0.7365
Enolase 2/NSE	8,214±1,238	10,427±981.1	11,465±1,642	0.3489	1.7046	0.492
VCAM-1	1,134,959±111,698	1,575,073±156,811	801,924±72,111	0.0714	0.0012**	0.0951
ICAM-1	358,177±68,845	398,929±82,388	553,296±116,675	0.4233	0.8172	2.1333
Fas	7,505±356.5	7,598±364	6,239±375.5	0.0618	0.0474*	2.5674

Notes: *$P<0.05$; **$P<0.01$; ***$P<0.001$.
Abbreviation: HC, healthy control.

Chemerin and Synuclein-alpha) were significantly different between AQP4+ group and controls.

Comparison of serum cytokine/chemokine levels between AQP4+ and MOG+ groups
Chemokines CC
There was no difference between serum AQP4+ and MOG+ groups for CC chemokines.

Chemokines CXC and IL
All measured chemokines CXC except CXCL6/GCP-2 showed no significant differences in serum AQP4+ group compared to MOG+ group.

Other cytokines
There was significant difference between serum AQP4+ and MOG+ groups for C5/C5a and Midkine. C5/C5a and Midkine were significantly higher in AQP4+ group compared to MOG+ group ($P<0.05$).

Discussion
NMO, characterized by ON and LETM, is an inflammatory demyelination disease of the CNS. AQP4-IgG is highly expressed in NMO and detected in the serum of 75% NMO patients.[24] Also previous study reported that about 10%–20% NMO patients shown negative expression to AQP4,[7] these patients often miss early treatment and thus suffer from condition aggravation.[8] With the technology improvement of AQP4 antibody detection, increase AQP4 seroprevalence and reverse results from negative expression to positive expression of AQP4,[25,26] there is emerging voice of doubt about NMO with negative expression of AQP4.[27] Some argued that the false negative of AQP4 is caused by methodological differences among different AQP4 antibody detection methods,[8,28] and relatively low AQP4 antibody titer,[27] which cannot be accurately detected. However, others insisted that NMO patients with true negative to AQP4 indeed exist, because still a large number of NMO patients with negative expression of AQP4 remained unchanged after antibody detection review. It is also suggested that NMO patients with positive AQP4 and negative AQp4 are different in the aspect of etiology, epidemiology and clinical presentation.[29,30] Astrocyte destruction peculiar to AQP4+ NMO patients does not appear in AQP4– NMO patients, implying that the pathogenesis of AQP4+ NMO and AQP4– NMO are different.[31–33]

Previous study reported that MOG is often present in NMO patients with negative expression of AQP4.[9] Different from AQP4 antibody specifically binding astrocytes with the participation of complements, MOG antibody specifically bind oligodendrocyte without a large amount of complement involvement, thus inflammatory response is not strong. Therefore, AQP4– NMO is a disease characterized by other autoantibodies such as MOG seroprevalence.[34] All in all, AQP4+ NMO and MOG+ NMO have different pathogenesis
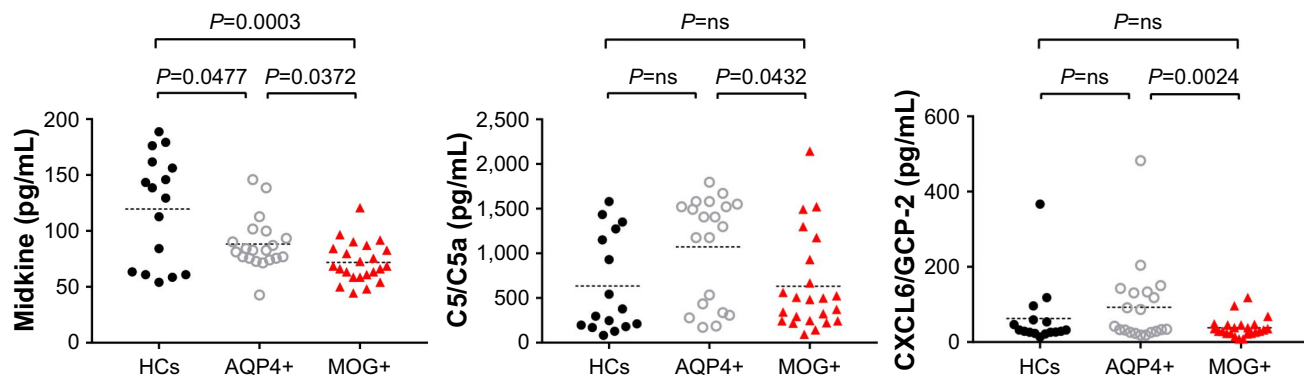
Figure 1 Serum chemokine concentrations that were found to be significantly modified between AQP4+ group and MOG+ group.
Abbreviations: HCs, healthy controls; AQP4+, aquaporin-4 antibody positive; MOG+, anti-myelin oligodendrocyte glycoprotein antibody positive; ns, not significant.

mechanism. In this study, from the aspect of cytokines and chemokines, ELISA was used to screen panels of cytokines and chemokines in NMO, and the comparison between experimental group and HC was made, as shown in Figure 1. It is found that CXCL6/GCP-2, Midkine and C5a probably may be key factors to distinguish the immunopathogenesis of AQP4+ NMO and MOG+ NMO.

The MK, a secretory heparin binding growth factor, is a low-molecular weight protein. For adults, MK is restricted to a certain organization. However, the expression of MK significantly increased in the process of tumorigenesis, inflammation and tissue cell repair.[35] MK was higher in AQP4+ group compared to MOG+ group, there were significant differences between the serum AQP4+ group and MOG+ group, which probably reveal the poor repair of cells in the inflammation process. However, this conclusion needs to be further verified because there is little research on the mean concentration level of midkine in NMO at present.

C5a is an activated component of the complement system, which in addition to playing an important role in the defense system, contributes to the amplification of inflammation. C5a was significantly higher in AQP4+ group compared to MOG+ group, indicating that C5a was involved in the immune response mechanism of NMO patients with positivity to AQP4 Ab. In another word, the immune reaction mechanism of AQP4+ NMO is different from MOG+ NMO.

CXCL6/GCP-2 is an important member of ELR + CXC chemokines family and has effects on the recruitment of cells such as neutrophils, hyaline leukocyte, macrophage and lymphocyte to site of inflammation contributing to inflammatory reaction. CXCL6/GCP-2 was significantly lower in AQP4+ group compared to MOG+ group, probably indicating that the inflammatory response is obviously relieved for AQP4+ NMO patients compared to MOG+

group. It shown that the immune reaction mechanism of NMO is different between patients with positivity to AQP4 Ab and with positivity to MOG Ab.

The limitations of our study are as following: 1) our AQP4 Ab POS and MOG Ab POS groups were not identical in clinical and demographic parameters. 2) The sample size was small in each group. Our control group aimed to generate normative data by using non-inflammatory neurological controls. And long-term storage of samples is probably result in theoretical degradation of cytokines/chemokines, although it was not clearly observe and identified. 3) Lacking of available stored frozen CSF samples, we could not perform comparisons between serum and CSF samples, thus it is not clear that whether the cytokine/chemokines are predominantly produced intrathecally or peripherally.

Conclusion

In summary, our study has roughly discussed the mean concentration change of chemokines and cytokine based on the serum AQP4+ and MOG+. The differences of mean concentration in CXCL6/GCP-2, Midkine and C5a probably reveal different immunologic mechanism between AQP4+ NMO and MOG+ NMO. In another word, CXCL6/GCP-2, Midkine and C5a may be influencing factors for NMO pathogenesis and provide guidance to monitor inflammation and response to treatment.

Abbreviations

ANA, antinuclear antibody; AQP4, aquaporin-4; AQP4+, patients seropositive for AQP4 antibodies; CBA, cell-based assay; CCR10, CC chemokine receptor-10; CNS, central nervous system; CTACK, cutaneous T cell-attracting chemokine; HCs, healthy controls; IDON, idiopathic demyelinating optic neuritis; LETM, longitudinally extensive transverse

myelitis; MK, midkine; MOG, myelin oligodendrocyte glycoprotein antibody; MOG+, patients seropositive for MOG antibodies; MS, multiple sclerosis; NMO, neuromyelitis optica; ON, neuritis optica; VCAM-1, vascular cell adhesion molecule 1.

Data sharing statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

Disclosure

The authors report no conflicts of interest in this work.

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