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Impact of Neuro-Behçet Disease Immunoglobulin G on Neuronal Apoptosis

IgG'nin Neurobehçet Hastalığında Nöronal Apoptozise Etkisi

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ABSTRACT

Introduction: Parenchymal neuro-Behçet disease (NBD) is encountered in 5%–15% of Behçet disease (BD) patients and is characterized by inflammation of the brainstem and diencephalon structures. Neuronal apoptosis has been shown to participate in neuronal cell loss. Anti-neuronal antibodies have been identified in NBD patients. However, the pathogenic properties of these antibodies have not been studied.

Methods: To delineate the potential pathogenic activity of serum antibodies on neurons, pooled sera from seven NBD patients and seven healthy controls were divided into purified immunoglobulin G (IgG) and IgG-depleted serum fractions, and each fraction was administered to cultured SH-SY5Y neuroblastoma cells. Cell death was evaluated with a toxicity assay and terminal deoxynucleotidyl transferase dUTP nick end labeling (TUNEL) staining. Moreover, expression levels of several apoptosis markers were evaluated with real time polymerase chain reaction (PCR).

Results: Administration of NBD IgG to cultured SH-SY5Y cells induced significantly increased cell death and apoptosis compared with other treatments. NBD IgG also enhanced the mRNA expression levels of major apoptosis and cell survival pathway factors.

Conclusion: Our results suggest that IgGs isolated from the sera of NBD patients have a neurotoxic activity that is presumably mediated by apoptotic mechanisms.

Keywords: Behçet disease, neuro-Behçet disease, immunoglobulin G, terminal deoxynucleotidyl transferase dUTP nick end labeling, neurotoxicity

ÖZ

Amaç: Behçet olgularının %5-15'inde beyinsapı ve diensefalon yapılarının inflamasyonu ile karakterize parenkimal nöro-Behçet hastalığı (NBH) ortaya çıkar. Nöronal apoptozun nöron kaybında rol oynadığı gösterilmiştir. Anti-nöronal antikorlar NBH olgularında gösterilmiş ancak bu antikorların patojenik özellikleri çalışılmamıştır.

Yöntem: Serum antikorlarının nöronlar üzerindeki olası patojenik etkilerinin incelenmesi amacıyla, 7 NBH olgusundan ve 7 sağlıklı kontrol olgusundan elde edilen serum havuzu saflaştırılmış Immunglobulin G (IgG) ve IgG'den yoksun serum fraksiyonlarına ayrıldı ve bu fraksiyonlar kültür ortamında büyütülmüş SH-SY5Y nöroblastoma hücrelerine uygulandı. Hücre ölümü toksisite deneyleri ile ve "terminal deoxynucleotidyl transferase dUTP nick end labeling" (TUNEL) boyaması ile değerlendirildi. Ayrıca, çeşitli apoptotik belirteçlerin ekspresyon düzeyleri gerçek zamanlı polimeraz zincir reaksiyonu (PZR) ile ölçüldü.

Bulgular: NBH IgG uygulaması, SH-SY5Y hücrelerinde, diğer uygulama gruplarına göre anlamlı derecede yüksek hücre ölümü ve apoptoz ile sonuçlandı. NBH IgG aynı zamanda belli başlı apoptoz ve hücre sağkalım yolak faktörlerinin mRNA ekspresyon düzeylerinin artmasına sebep oldu.

Sonuç: Sonuçlarımız NBH olgularının serumlarından elde edilen IgG-lerin nörotoksik bir etkisi olduğunu göstermektedir. Bu nörotoksik etki muhtemelen apoptotik mekanizmalar üzerinden gerçekleşmektedir.

Anahtar Kelimeler: Behçet hastalığı, Nöro-Behçet hastalığı, immunglobulin G, terminal deoxynucleotidyl transferase dUTP nick end labeling, nörotoksisite

INTRODUCTION

Behçet disease (BD) is an inflammatory disorder that is characterized by recurrent oral aphthae, genital ulcerations, and uveitis. In addition, other organs, including the central nervous system (CNS), might be affected in BD patients (1). BD with CNS involvement, also known as neuro-BD (NBD), is encountered in 5%–15% of BD patients in parenchymal or vascular forms. Parenchymal NBD is most typically characterized by inflammatory lesions that extend from the brainstem to the thalamus, diencephalon, basal ganglia, and internal capsules (2,3).

Parenchymal NBD is generally caused by large brain lesions with infiltrating macrophages, neutrophils, and lymphocytes, and neuronal apoptosis appears to be an important contributor to neuronal destruction in these lesions (1,2,3). However, many BD patients with no demonstrable

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Table 1. Primers used in real time polymerase chain reaction (PCR) analysis of SH-SY5Y cells

Primer name	Forward primer sequence (5'-3')	Reverse primer sequence (3'-5')
Bax	TGGAGCTGCAGAGGATGATTG	GAAGTTGCCGTCAGAAAACATG
Bcl-2	CATGTGTGTGGAGAGCGTCA	TCACTTGTGGCCCAGATAGG
Caspase 3	ATTGTGGAATTGATGCGTGA	GGCAGGCCTGAATAATGAAA
Caspase 9	GCTGTTCAGGCCCCATATGAT	GGACTCACGGCAGAAGTTCA
Akt-1	CTTCTTTGCCGGTATCGTGT	CTGGCCGAGTAGGAGAACTG
mTOR	CTCATCAGCATTAATAATAAGC	GTGTCCATTTTCTTGTCATAG
DJ1	GGAGACGGTCATCCCTGTAG	TTCACAGCAGCAGACTCAGA
GAPDH (housekeeping)	GAAGGTGAAGGTCGGAGTCA	GACAAGCTTCCCGTTCTCAG

GAPDH: glyceraldehyde-3-phosphate dehydrogenase; mTor: mechanistic target of rapamycin

brain lesions develop neurological symptoms (4,5). Anti-neuronal antibodies might putatively cause these symptoms in the absence of evident brain inflammation. Although antibodies to various heat-shock proteins, neuronal membrane antigens, and apoptosis factors have been identified in BD and NBD patients, the pathogenic significance of these antibodies has never been studied (6,7,8,9). To demonstrate the potential pathogenicity of these antibodies, serum immunoglobulin G (IgG) and IgG-depleted sera of NBD patients were administered to cultured SH-SY5Y neuroblastoma cells, and the potential neurotoxicity of anti-neuronal IgG from NBD patients was analyzed by in vitro studies.

METHODS

Sera and Anti-Neuronal Antibody Assays

The sera of seven parenchymal NBD patients who fulfilled the diagnostic criteria for BD (10) and those of seven age-/gender-matched healthy controls were used. The sera were frozen at −80°C until assayed. The study was approved by the Ethics Committee of Istanbul Faculty of Medicine of Istanbul University. Informed consent was obtained from all participants.

IgG purification and IgG depletion

IgGs were isolated from pooled healthy and NBD sera using a protein A–sepharose CL-4B column (Sigma, St. Louis, MO), as previously reported (11). In brief, 1 ml of serum was incubated with 0.5 ml of protein A–sepharose for 2 h at room temperature (RT). After removing the serum, IgG was extracted using 0.05 M citrate buffer at pH 3.0 and immediately neutralized with 1.5 M Tris-buffer at pH 8.8. The IgG-containing solution was then dialyzed against phosphate-buffered saline (PBS) and filter sterilized. To obtain IgG-depleted serum, the serum was recovered from the protein A column by centrifuging the column for 2 min at 500 rpm. The recovered serum was reabsorbed on a protein A–sepharose column for 2 h at RT and recovered by centrifugation. Each serum was reabsorbed four times. IgG depletion in the reabsorbed sera was confirmed by the absence of IgG bands in the expected molecular weight range (45–55 kDa for heavy chains and 25–35 kDa for light chains) by gel electrophoresis. Protein concentrations of purified IgG solutions were measured using the Bradford method.

Neuroblastoma Cell Line and Toxicity Assay

The neuroblastoma cell line (SH-SY5Y) (ATCC, Wesel, Germany) was grown in minimal essential medium with F12-nutrient mixture (MEM/F-12), supplemented with non-essential amino acids (Sigma-Aldrich, St. Louis, MO, USA). A toxicity assay was performed to assess growth inhibitory and cytolytic effects of serum and serum IgG on neuroblastoma cells in culture. IgG-depleted sera of NBD and healthy control groups were diluted four times with culture medium and filter-sterilized. Likewise, purified IgG solutions (10 µg/µL protein concentration) from NBD patients and healthy controls were diluted four times with culture medium. SH-SY5Y cells were seeded in six-well plates at a concentration of 50000 cells/well. After 16 h, the medium was replaced with 2 mL of culture medium containing NBD patient/healthy control IgG-depleted serum, purified IgG samples, or PBS alone. After 72 h of incubation, the medium was removed and cells were washed with PBS and trypsinized for 5 min at 37°C. After neutralizing the trypsin with 1 mL of media, cell counts were obtained using a Coulter counter ZM connected to a Coulter channelyzer 256 (Beckman Coulter, Brea, CA, USA). All studies were performed in six wells; cells from each of the six wells, incubated with a specific serum or IgG sample, were counted three times and the mean value was obtained. The mean value for each treatment group was expressed as a percentage of the control wells treated with PBS only using the following formula; (mean cell count of the six wells incubated with specific serum or IgG/mean cell count of the six wells incubated with PBS) × 100.

Terminal Deoxynucleotidyl Transferase dUTP Nick end Labeling (TUNEL) Staining

The apoptosis intensity of SH-SY5Y cells treated with NBD patients' or healthy individuals' IgG and serum samples was estimated by TUNEL staining as per the manufacturer's protocol (Roche Applied Science, Indianapolis, IN, USA).

Real Time Polymerase Chain Reaction (PCR)

Total RNA was obtained from SH-SY5Y cells using TRIzol and reverse transcribed into complementary DNA with a RevertAid First Strand cDNA Synthesis Kit (Thermo Fisher Scientific, Waltham, MA USA). Quantitative PCR was performed using 2 µL of cDNA, 1 µL ddH2O, 5 µL SYBR Green PCR Master Mix (Applied Biosystems, Waltham, MA USA), and 1 µL of forward and reverse primers (Table 1). All samples were studied in triplicate and the mRNA abundance was normalized for each sample to the amount of glyceraldehyde-3-phosphate dehydrogenase (GAPDH). RT-PCR and melting curve analysis were performed with a LightCycler 480 II (Roche Diagnostics, Mannheim, Germany) instrument. Data were analyzed according to the ΔΔCt method and the results were expressed as relative mRNA levels.

Statistical Analysis

Multiple group comparisons were performed using the ANOVA multiple comparison test and Tukey's post-hoc test. A p value of <0.05 was considered statistically significant.

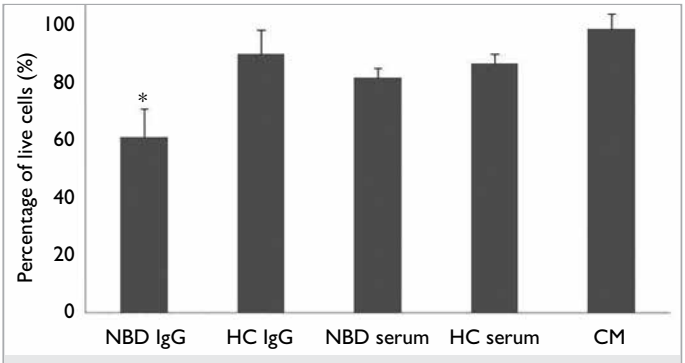

Figure 1. Toxicity of IgG and IgG-depleted serum obtained from neuro-Behçet disease (NBD) patients and healthy controls (HC). Counts of SH-SY5Y cells treated for 72 h with pooled NBD and HC IgG or IgG-depleted serum were calculated and expressed as a percentage of the count of control SH-SY5Y cells treated with culture medium (CM) only. *p<0.05 by ANOVA. Vertical bars indicate standard errors

RESULTS

Clinical and Demographic Features of Patients

Pooled sera of seven NBD patients (one woman and six men; mean age±standard deviation, 37.2±4.1) and those of 7 seven age-/gender-matched healthy controls were used for all in vitro studies. The average disease duration of NBD patients was 6.9±2.1 years, and the Expanded Disability Status Scale scores ranged between 2.0 and 4.5 (2.7±0.9). During blood sampling, NBD patients did not experience an attack and were not under immunosuppressive treatment.

NBD IgG Administration Increases Neuronal Cell Death and Alters Apoptosis Parameters

Counts of SH-SY5Y cells were significantly reduced in NBD-IgG-treated wells compared with other treatment arms at 72 h of incubation time (p<0.05 by ANOVA). In NBD-IgG-treated wells, an average of approximately 40% reduction was observed in total cell counts (Figure 1). Two-group comparisons were significant for NBD-IgG-treated cells versus other treatment arms (p<0.05 for all by Tukey's post hoc analysis). There were no significant differences between other treatment arms in terms of cell counts.

To evaluate the involvement of apoptosis in neuronal cell loss, TUNEL staining was performed for SH-SY5Y cells treated with the same treatment arms. Only cells treated with NBD IgG showed an abundance of apoptotic cells (4–7 cells in each ×10 microscope field). In cells treated with healthy control serum, healthy control IgG, NBD serum, or culture medium, much fewer apoptotic cells were observed (<1 cell per ×10 microscope field) (Figure 2). These results suggested that NBD IgG (but not IgG-depleted sera of NBD patients) reduces neuronal survival by enhancing apoptosis.

NBD IgG Administration Enhances Apoptotic and Anti-Apoptotic Factor Expression Levels

To analyze the impact of NBD IgG and serum samples on neuronal apoptosis and survival pathway factor expression, mRNA levels of a panel of intracellular apoptosis factors were measured. NBD-IgG-treated cells (for 72 h) demonstrated significantly increased mRNA levels of pro-apoptotic Bax, caspase 3, and caspase 9 compared with cells treated with healthy control serum, healthy control IgG, NBD serum, or culture medium (p<0.01 for all three parameters with ANOVA). Notably, expression lev-

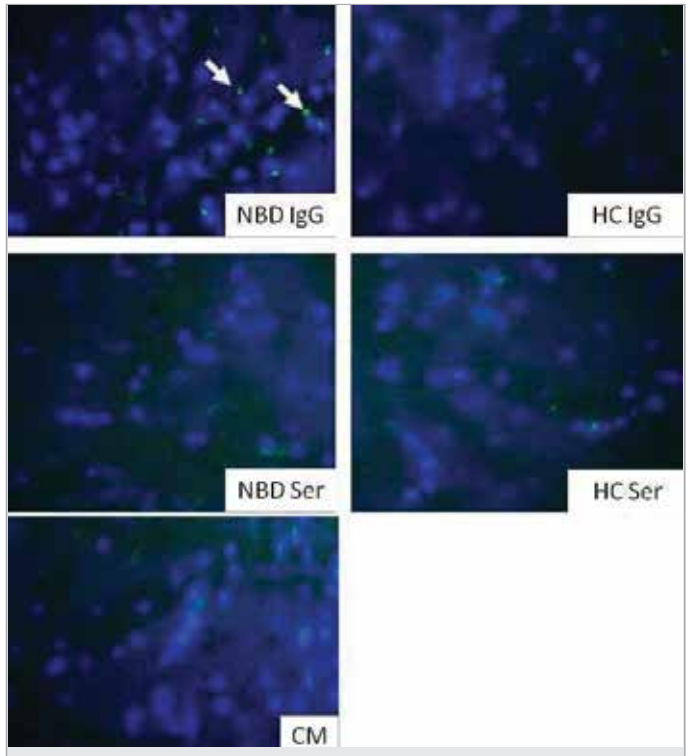

Figure 2. Evaluation of apoptotic SH-SY5Y cells by TUNEL staining, following 72 h of incubation with IgG and IgG-depleted serum obtained from neuro-Behçet disease (NBD) patients and healthy controls (HC). Cells treated with only culture medium (CM) were used as controls. White arrows indicate apoptotic nuclei (green), whereas DAPI counterstaining (blue) shows nuclei of intact cells (original magnification ×40)

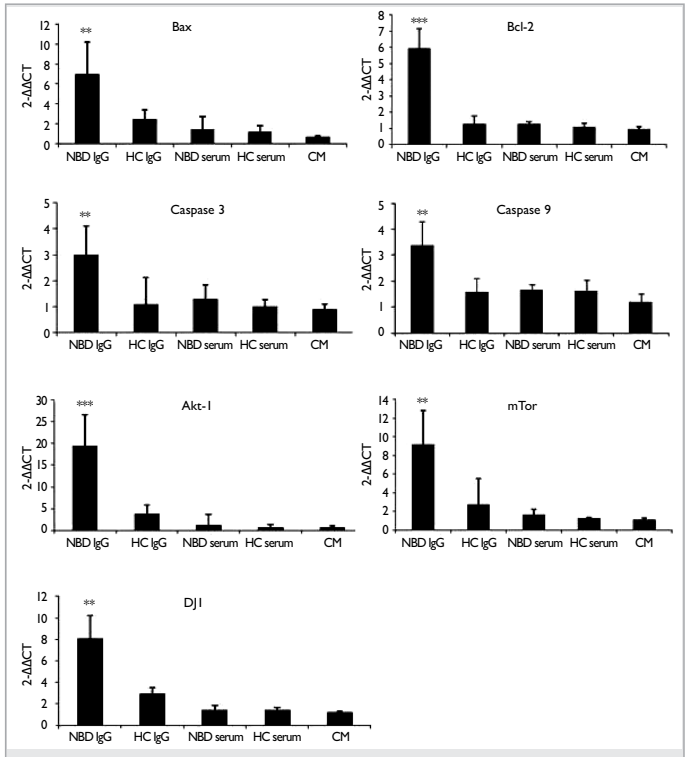

Figure 3. Relative mRNA expression levels of apoptosis and survival pathway factors in cultured SH-SY5Y cells treated with only culture medium (CM) or IgG and IgG-depleted serum obtained from neuro-Behçet disease (NBD) patients and healthy controls (HC)

**p<0.01 and ***p<0.001 by ANOVA. Vertical bars indicate standard errors

els of anti-apoptotic Bcl-2 were also increased in SH-SY5Y cells treated with NBD IgG but not in those treated with other treatment ($p<0.001$ with ANOVA). Moreover, expression levels of the anti-apoptotic components of the phosphoinositide 3-kinase (PI3K)/Akt pathway Akt-1, mechanistic target of rapamycin (mTOR), and DJ1 were increased in NBD-IgG-treated cells compared with other treatment groups ($p<0.01$ for mTor and DJ1 and $p<0.001$ for Akt-1 by ANOVA) (Figure 3). Two-group comparisons were significant for NBD-IgG-treated cells versus other treatment arms ($p<0.01$ for all by Tukey's post hoc analysis). There were no significant differences between other treatment arms in terms of mRNA expression levels.

DISCUSSION

In our study, with multiple independent methods, we showed that serum NBD IgG has a neurotoxic activity and effectively prevents the proliferation of neurons. Our real time PCR data indicated that the neurotoxic activity could be because of an interference with intracellular apoptosis and survival pathways. Moreover, the absence of any neurotoxic activity with IgG-depleted serum indicates that IgG, but not any other humoral factor (e.g., cytokines and granzyme), is involved in this toxic effect. Only a few reports have demonstrated the beneficial effects of antibody-depleting treatment methods (e.g., plasma exchange and intravenous immunoglobulin) in BD patients (12,13). The demonstration of neurotoxic IgG in our study supports this notion and suggests that these treatment methods also work for NBD.

Apoptotic neuronal death is a remarkable pathological finding observed in brain lesions of NBD patients. Unlike other neuroinflammatory disorders, extensive neuronal loss is observed in NBD lesions, in addition to T-cell, B-cell, and monocyte infiltration (14). Although pro-apoptotic cytokines, such as IL-6, have been implicated in neuronal apoptosis, this view has not been supported with experimental data (14). Our results suggest that serum IgG is the real culprit for this phenomenon.

The PI3K/Akt pathway is a major survival pathway and is notably located within the apoptosis, autophagia, and mitochondrial pathways (15). Akt-1, mTor, and DJ1, factors of the PI3K/Akt pathway, have anti-apoptotic activity, and in animal models of neurotoxicity, the reduced expression of these molecules has been associated with increased neuronal loss (16,17). In several clinical and experimental studies, the activation of the PI3K/Akt pathway has been shown to lead to increased anti-apoptotic bcl-2 gene expression and subsequently, reduced caspase gene expression (15,16,17).

In line with the toxicity and TUNEL staining assays, NBD-IgG-treated SH-SY5Y cells showed increased mRNA expression levels of pro-apoptotic factors, Bax, caspase 3, and caspase 9. However, notably, expression levels of anti-apoptotic factors, Bcl-2, Akt-1, mTor, and DJ1, were also increased in NBD-IgG-treated cells. These results indicate that the anti-apoptotic and survival pathways are activated as a compensating measure to overcome the toxic activity of NBD IgG. In several previous reports, the compensating increased Akt-1 expression has been documented (18,19). Similar to our experimental setting, this increase has not been effective in preventing cell death.

In conclusion, our study demonstrated for the first time the neurotoxic and pro-apoptotic activity of NBD IgG. These findings not only shed new light on NBD pathogenesis but also emphasize the potential benefits of antibody-depleting treatment methods for NBD patients. Better understanding of the apoptosis pathways involved in NBD-related neuronal loss in future studies might lead to the innovation of novel apoptosis-inhibiting treatment methods for this potentially disabling neurological inflammatory disease.

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Informed Consent: Written informed consent was obtained from all participants who participated in this study.

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REFERENCES

1. Gül A. Pathogenesis of Behçet's disease: autoinflammatory features and beyond. Semin Immunopathol 2015; 37:413-418.
2. Saip S, Akman-Demir G, Siva A. Neuro-Behçet syndrome. Handb Clin Neurol 2014; 121:1703-1723.
3. Akman-Demir G, Serdaroglu P, Tasçi B. Clinical patterns of neurological involvement in Behçet's disease: evaluation of 200 patients. The Neuro-Behçet Study Group. Brain 1999; 122:2171-2182.
4. Yesilot N, Shehu M, Oktem-Tanor O, Serdaroglu P, Akman-Demir G. Silent neurological involvement in Behçet's disease. Clin Exp Rheumatol 2006; 24:S65-S70.
5. Akman-Demir G, Mutlu M, Kiyat-Atamer A, Shugaiv E, Kurtuncu M, Tugal-Tutkun I, Tuzun E, Eraksoy M, Bahar S. Behçet's disease patients with multiple sclerosis-like features: discriminative value of Barkhof criteria. Clin Exp Rheumatol 2015; 33:S80-S84.
6. Vural B, Uğurel E, Tüzün E, Kürtüncü M, Zuliani L, Cavuş F, Içöz S, Erdağ E, Gül A, Güre AO, Vincent A, Ozbek U, Eraksoy M, Akman-Demir G. Anti-neuronal and stress-induced-phosphoprotein 1 antibodies in neuro-Behçet's disease. J Neuroimmunol 2011; 239:91-97.
7. Vural B, Sehitoğlu E, Cavuş F, Yalçınkaya N, Haytural H, Küçükerden M, Ulusoy C, Uğurel E, Turan S, Bulut L, Türkoğlu R, Shugaiv E, Kürtüncü M, Atakan S,

Güre AO, Gül A, Eraksoy M, Akman-Demir G, Tüzün E. Mitochondrial carrier homolog 1 (Mtch1) antibodies in neuro-Behçet's disease. J Neuroimmunol 2013; 263:139-144.
8. Taşçi B, Direskeneli H, Serdaroglu P, Akman-Demir G, Eraksoy M, Saruhan-Direskeneli G. Humoral immune response to mycobacterial heat shock protein (hsp)65 in the cerebrospinal fluid of neuro-Behçet patients. Clin Exp Immunol 1998; 113:100-104.
9. Gheita TA, Samir H, Hussein H. Anti-annexin V antibodies in neuro-Behçet patients: clinical significance and relation to disease activity. Int J Rheum Dis 2012; 15:e124-e126.
10. International Study Group for Behcet's Disease. Criteria for diagnosis of Behcet's disease. Lancet 1990; 335:1078-1080.
11. Furneaux HM, Rosenblum MK, Dalmau J, Wong E, Woodruff P, Graus F, Posner JB. Selective expression of Purkinje-cell antigens in tumor tissue from patients with paraneoplastic cerebellar degeneration. N Engl J Med 1990; 322:1844-1851.
12. Seider N, Beiran I, Scharf J, Miller B. Intravenous immunoglobulin therapy for resistant ocular Behçet's disease. Br J Ophthalmol 2001; 85:1287-1288.
13. Lambert D, Rifle G, Guiod-Deschamps I, Collet E. Plasma exchange in patients with Behçet's disease. J Am Acad Dermatol 1990; 22:1123.
14. Hirohata S, Arai H, Matsumoto T. Immunohistological studies in neuro-Behçet's disease. Adv Exp Med Biol 2003; 528:385-387.
15. Kim RH, Smith PD, Aleyasin H, Hayley S, Mount MP, Pownall S, Wakeham A, You-Ten AJ, Kalia SK, Horne P, Westaway D, Lozano AM, Anisman H, Park DS, Mak TW. Hypersensitivity of DJ-1-deficient mice to 1-methyl-4-phenyl-1,2,3,6-tetrahydropyrindine (MPTP) and oxidative stress. Proc Natl Acad Sci U S A 2005; 102:5215-5220.
16. Malagelada C, Jin ZH, Greene LA. RTP801 is induced in Parkinson's disease and mediates neuron death by inhibiting Akt phosphorylation/activation. J Neurosci 2008; 28:14363-14371.
17. Vanhaesebroeck B, Guillermet-Guibert J, Graupera M, Bilanges B. The emerging mechanisms of isoform-specific PI3K signalling. Nat Rev Mol Cell Biol 2010; 11:329-341.
18. Li X, Li Z, Zhou W, Xing X, Huang L, Tian L, Chen J, Chen C, Ma X, Yang Z. Overexpression of 4EBP1, p70S6K, Akt1 or Akt2 differentially promotes Coxsackievirus B3-induced apoptosis in HeLa cells. Cell Death Dis 2013; 4:e803-e809.
19. Bai B, Liu HQ, Chen J, Li YL, Du H, Lu H, Yu PL. Construction of the subtracted cDNA library of striatal neurons treated with long-term morphine. Chin Med Sci J 2011; 26:54-59.