Original Research Article

THE IMPORTANCE OF INCREASED SERUM ORNITHINE LEVELS IN THE PATHOGENESIS OF ALZHEIMER AND PARKINSON'S DISEASES

Running title: Arginine catabolism effects on neuroinflammation.

ABSTRACT

Background : The aim of this study was to investigate the levels of enzymes and ornithine involved in the synthesis of polyamines in patients with Alzheimer's and Parkinson's disease and to see their positive or negative effects on the modulation of the immune system

Methods: Thirty-five healthy subjects as control group and 35 patients with Alzheimer's and Parkinson's disease were included in this study. Determination of Ornithine decarboxylase, Arginine Decarboxylase and Agmatinase levels were evaluated by using Enzyme Linked Immunosorbent Assay (Elisa kit). Ornithine levels were measured spectrophotometrically.

Results: When ornithine levels of Alzheimer and Parkinson patients were compared to the control group, differences were found as significant ($p<0.05$). On the other hand, when Ornithine decarboxylase, Arginine Decarboxylase, Agmatinase levels of Alzheimer and Parkinson patients were compared to the control group, the differences were found as insignificant ($p>0,05$).

Conclusion: Although the enzyme levels in the pathway of polyamine synthesis in Alzheimer's and Parkinson's diseases do not change, the increase in ornithine level will not contribute to the fight

mode of the immune system. On the contrary, it may change plasticity by increasing osmolality.

Key words: Alzheimer, Parkinson, Polyamine, Ornithine, Agmatine, Immunmodulation

INTRODUCTION

Alzheimer's and Parkinson's disease are two of the most common neurological diseases that cause neurodegeneration and affect many people [1]. The most valid hypothesis explaining the development of Alzheimer's disease (AD), the most common neurological disease, is the amyloid cascade hypothesis. According to this hypothesis, amyloid-β peptides (Aβ) accumulate in the cerebral blood vessels and brain parenchyma, and accumulation of hyperphosphorylated tau proteins in neurons leads to lethal disease, progressive loss of consciousness, functional impairment and memory loss [2,3]. Parkinson's disease, which is the second most common neurological disease that occurs after death of dopaminergic neurons in Substantia nigra pars compacta, causes rigidity, tremor and hypokinesia [4,5]. In addition, α-synuclein protein, which accumulates in neurons, plays a key role in Parkinson's disease. Lewy particles, which are caused by excessive accumulation of this protein in neurons, lead to pathology leading to disease progression in cholinergic and monoaminergic neurons in the brain. The diagnosis of idiopathic Parkinson's disease can be determined by applying these two major neuropathologies (neuronal loss in specific areas of the substantia nigra and widespread intracellular protein (α-synuclein) accumulation [6). In Alzheimer's disease, a different pattern of α-synuclein pathology was found to accumulate mainly in the limbic region of the brain [7]. In vitro experiments have shown that the presence of polyamines in α-synuclein accumulation and fibril formation is effective and this effective sequence has been shown

as spermin>spermidine>putrescine [8]. Although the mechanism of brain atrophy and neuronal loss is not fully known, there is a growing body of evidence recently that the lack of arginine and suppressing immunity play a critical role in the pathogenesis of AD [9]. The cells responsible primarily for the immune system in the brain are microglia cells and macrophage-like immune cells found in the brain parenchyma, which are involved in the modulation of the brain's inflammatory response [10]. The microglia are activated immediately after the ischemia. Circulating monocytes are rapidly transformed into macrophages in the brain via blood-brain barrier due to inflammation [10,11]. Microglia and macrophages are known to be essential cells in inflammation after cerebral ischemia. Polyamines have a negative regulatory effect on macrophage activation through complex associations with NO metabolism. In macrophages, NO is an intermediate product in the L-arginine oxidation process [12].

Polyamines are molecules having 2, 3 or 4 amino groups. They are widely found in living organisms because they have a key role in the survival of life [13]. The major polyamines synthesized by several enzymes from the amino acid of L-Arginine are putrescine, spermidine, spermine and agmatine (Fig 1]. Polyamines play an important role in biological processes because of their interaction with many different receptors, protein kinases, nucleotide cyclases. It has been reported that the increase in the levels of polyamines may be associated with diseases such as cancer, as they have a key role in growing and dividing the cell [14,15,16]. However, due to their interaction with systems such as polyamines, catecholamines, GABA, nitric oxide (NO), glutamate, they are also associated with many psychiatric disorders, especially schizophrenia [16,17,18]. The survival of the cells that make up the organism depends on the presence of polyamines. It is known that neurodegenerative diseases

caused by cell death develop due to the differentiation of polyamine metabolism [19,20,21]. Many researchers have shown that agmatine has neuroprotective potential and develops a cognitive function in various animal models of central nervous system damage such as neurotrauma and neonatal ischemia [22,23,24,25,26]. The degraded polyamine metabolism indirectly causes the degradation of nitric oxide synthase. Increased agmatine synthesis causes suppression of NO synthesis in immunocytes and leads to defense deficiency, while decreased levels result in increased NO synthesis resulting in neurodegeneration and death of neurons (Figure 1) [27,28,29] .

Our aim in this study was to reveal the possible roles of polyamines in the pathogenesis of Alzheimer and Parkinson diseases. For this purpose, the levels and effects of arginine decarboxylase, ornitine decarboxylase, agmatinase and ornitine involved in the pathway of polyamine synthesis on the immune system were examined.

MATERIALS AND METHODS:

Patient and Control Group

The 35 patients, who applied to the Cumhuriyet University Medicine Faculty Neurology Policlinic and took diagnosis with alzheimer and parkinson, were included in the study as experimental group. It was not made any restriction in terms of the gender and age. Our control group was chosen from the 35 healthy individuals who have not any systemic diseases (diabetes, hypertension and neurodegenerative disease).

Blood Samples Collection

Blood samples were taken from the controls and patients who were made the diagnosis of alzheimer and parkinson and not receive any therapy. The serums were obtained by centrifugation at 1610 x g for 10 minutes of the blood samples were preserved in 80 0C for to study.

Detection of enzyme levels

Ornithine, arginine decarboxylase, ornithine decarboxylase and agmatinase levels have been measured in serum of alzheimer and parkinson patients. Ornithine level were calculated spectrophotometrically at 515 nm using the method defined by Chinard and the value was given as µmol/ml [30]. Arginine decarboxylase, ornithine decarboxylase and agmatinase levels were determined by ELISA kit according to the manufacturer's protocol (SunRed, China).

Statistical Analysis

Mann Whitney U test was used for statistical analysis of the data. The data were stated in the tables as the arithmetical average ± Standard deviation and the level of significance was taken as 0,05

RESULTS

There wasn't any significant difference between patient groups and control group in terms of gender and age ranges (P>0,05) (Table 1). When ADC, ODC and Agmatinase enzymes, which were determined at serum levels, were compared according to the control group, no statistically significant difference was found between the two disease groups (Alzheimer and Parkinson) (P>0,05) (Table 2).

On the other hand, serum ornithine levels increased in both groups when compared with the control group, and they were statistically significant. $P<0.05$ (Table 2).

DISCUSSION:

In this study, enzymes (ADC, ODC and Agmatinase) and ornithine levels in polyamine synthesis pathway were measured in serums of Alzheimer and Parkinson's patients. When the levels of the enzymes were compared with the control as a result of analysis, no significant difference was found between the two groups of patients and control ($p>0,05$). Ornithine was higher and statistically significant in both groups when compared to the control group ($p<0,05$). Enzyme and ornithine levels in the polyamine synthesis pathway have been investigated in this study for the first time in serums of Alzheimer and Parkinson's patients. Most of the studies carried out to date regarding polyamines and their relation to these diseases are in the form of experimental animals and postmortem studies. In one postmortem study, the amount of spermidine increases in the temporal cortex (70%) and reduction in levels of putrescine (28%) were found in patients with AD [19]. In another postmortem study, there was no difference in spermidine and spermine concentrations in the basal ganglia of parkinson, huntington's disease (HD) and progressive supranuclear palsy (PSP) patients and it was found to decrease with age [31]. Changes in the homeostasis of polyamines play an important role in the emergence of many diseases such as cell growth, senility, memory performance, neurodegenerative diseases, metabolic diseases and cancer [32,33].

In the polyamine synthesis pathway, two major molecules play an important role in the modulation of the immune system. These are ornithine and agmine molecules. Ornithine is the

120 precursor molecule of the synthesis of major polyamines (putresin, spermidine and spermine), the
121 precursor of both L-glutamate and GABA molecules as well as the precursor of L-proline required for
122 the synthesis of connective tissue for wound healing (Figure 1). In this study, ornithine levels were
123 increased in both groups of patients compared to the control and statistically significant ($p<0.05$).
124 The major metabolic ways in which the increased ornithine can go, are L-proline, L-glutamate, GABA,
125 polyamine synthesis and urea cycle. Since the ODC levels, the rate limiting enzyme in polyamine
126 synthesis, did not change in both patient groups, the polyamine synthase pathway would not be
127 active (Table 2).

128 The entry of the increased ornithine into the urea cycle will contribute to the formation of excessive
129 urea and thus the increase of osmolarity in many regions of the brain such as the cerebellum,
130 cerebral cortex and brain stem [34]. Chronic osmotic pressure caused by ornithine also modifies
131 plasticity in the hippocampal region by mediating tonic inhibition of the GABA receptor family
132 [18,35,36]. On the other hand, the increase of L-proline synthesis for collagen production, which is
133 necessary for connective tissue, means that immune system cells pass into the fix mode (wound
134 healing). Thus, increased L-proline synthesis will only contribute to the synthesis of collagen [37].
135 The main problems of both Parkinson and Alzheimer's patients are mainly a cluster of α-synuclein
136 and AB. Extra collagen accumulation will also increase the negative effect. This approach could not
137 be verified for the time being because L-prolin levels could not be measured due to the limitations of
138 the study. Another molecule that is effective in the modulation of immune cells is agmatine. The
139 active immunocytes (microglia, macrophage) increase NO production in the M1 (fight-killing
140 program) mode. They do this via inducible nitric oxide synthase (iNOS). NO is a twisted sharp knife;

141 The first is the main events caused by their decreasing concentration. These are reduced vasculer
142 perfusion, blockage of granulocytes in the blood vessels in the inflamed area, inhibition of pro-
143 inflammatory reactions, and thickening of the capillary membranes [38,39,40]. All these adverse
144 events lead to neurodegeneration and neuronal cell death due to inadequate O2 and glucose
145 transport to the resulting neuronal and glial cells [41]. In the second, high concentrations of NO
146 inhibit many complexes in the respiratory chain and lead to an increase in the synthesis of highly
147 toxic compound peroxynitrite ($ONOO^-$). This highly toxic compound causes mitochondrial damage
148 and leads to mitochondrial dysfunction leading to neurodegeneration and neuronal cell death [42].
149 When the level of arginine is reduced to an undetectable level in regions with inflammation, it is
150 mean that Arginine metabolism is a central pathway for macrophages in the immune system [43].
151 When inflammation occurs, the macrophages must be directed to one of the "fight" or "fix" modes.
152 Fight is a killing program (eg pathogen) and fix is a wound healing program. The Fight pathway
153 activated by macrophages results in the formation of nitric oxide (NO) and cell proliferation is
154 inhibited [44]. When the fix pathway is activated, proliferation and healing process is initiated by
155 ornithine formation (via polyamine and collagen) [45,46,47,48]. Both the M1 (fight) and M2 (fix)
156 pathways use arginine, but the NO and Ornithine pathways can not be active at the same time
157 because the metabolites of a pathway inhibit the enzymes of the other pathway (Şekil 1). The fact
158 that ADC enzyme levels which are effective in the synthesis of agmatine in both groups of patients
159 do not change and that there is no difference in agmatinase enzyme in the destruction pathway will
160 not change the amount of agmatine (Tablo 2). Solubulous amyloid-Beta oligomers are responsible
161 for synapse loss and neurodegenerative development in Alzheimer's disease [49]. B-Amyloid 1-40

peptide regulates glutamate release by acting on glutamergic terminals [50], while B-amyloid plaques lead to increased intracellular Ca concentration and death of neurons by directly affecting on NMDA receptors [51].

The absence of an increase in the amount of agmatine, the natural antagonist of the receptors, naturallyi nhibits blockage of these receptors.

Agmatin activates eNOS while inhibiting iNOS from NOS enzymes, studies on experimental animal models showed that application of agmatine in brain cells damaged by lipopolysaccharide reduced and corrected the damage with these properties [52,53,54,55].

As a result, polyamin synthesis enzymes whose levels are not altered in Alzheimer and Parkinson's disease can not contribute to the prevention of neurodegeneration. Increased ornithine levels may contribute to proline, glutamate, GABA and urea synthesis and increase osmolarity and impair plasticity. Exposing these darker aspects with more extensive studies may allow new approaches to be introduced in the treatment of such diseases

Acknowledgments: This research did not receive any specific grant from any funding agency in the public, commercial or not-for-profit sector.

Conflict of Interest/Disclosure Statement: The authors have no conflict of interest to report.

REFERENCES:

1. Lleó A, Cavedo E., Parnetti L, Vanderstichele H, Herukka SK, Andreasen N, Ghidoni R, Lewczuk P, Jeromin A, Winblad B, Tsolaki M, Mroczko B1, Visser PJ, Santana I, Svenningsson P, Blennow K, Aarsland D, Molinuevo JL, Zetterberg H, Mollenhauer B. (2015) Cerebrospinal fluid biomarkers in trials for Alzheimer and Parkinson diseases. Nature Reviews Neurology 11(1), 41-55.

2. Querfurth, HW. & LaFerla FM. (2010) Alzheimer's disease. N. Engl. J. Med. 362, 329–344.

3. Hardy J, & Selkoe DJ. (2002) The amyloid hypothesis of Alzheimer's disease: progress and problems on the road to therapeutics. Science 297, 353–356.

4. Conway KA, Harper JD, Lansbury PT. (1998)Lansbury Accelerated in vitro fibril formation by a mutant alpha-synuclein linked to early-onset Parkinson disease Nat Med 4, 1318–1320.

5. Klein C, & Schlossmacher MG. (2007). Parkinson disease, 10 years after its genetic revolution: multiple clues to a complex disorder. Neurology 69(22), 2093-2104.

6. Poewe W, Seppi K, Tanner CM, Halliday GM, Brundin P, Volkmann J, Schrag AE, Lang AE. (2017). Parkinson disease. Nature Reviews Disease Primers 3, 17013.

7. Iacono D, Geraci-Erck M, Rabin ML, Adler CH, Serrano G, Beach TG, Kurlan R. (2015)Parkinson disease and incidental Lewy body disease Just a question of time? Neurology 85(19), 1670-1679.

8. Antony T, Hoyer W, Cherny D, Heim G, Jovin TM, & Subramaniam V. (2003) Cellular polyamines promote the aggregation of α-synuclein. Journal of Biological Chemistry 278(5), 3235-3240.

9. Kan MJ, Lee JE, Wilson JG, Everhart AL, Brown CM, Hoofnagle AN, Jansen M, Vitek MP, Gunn MD, Colton CA. (2015) Arginine deprivation and immune suppression in a mouse model of Alzheimer's disease. Journal of Neuroscience 35(15), 5969-5982.

10. Ginhoux F, Lim S, Hoeffel G, Low D, Huber T. (2013) Origin and differentiation of microglia. Front Cell Neurosci.7:45. doi:10.3389/fncel.2013.00045.

11. Bonaventura A, Liberale L, Vecchié A, Casula M, Carbone F, Dallegri F, Montecucco F. (2016) Update on inflammatory biomarkers and treatments in ischemic stroke.Int J Mol Sci. 17(12):E1967. doi:10.3390/ijms17121967.

12. Marletta MA, Yoon PS, Iyengar R, Leaf CD, Wishnok JS. (1988) Macrophage oxidation of L-arginine to nitrite and nitrate: Nitric oxide is an intermediate. Biochemistry 27: 8706–8711.

13. Tabor CW, Tabor H (1984) Polyamines. Annu Rev Biochem, 53: 749-790.

14. Bachrach U. (2004) Polyamines and cancer: minireview article. Amino Acids 26: 307-309.

15. Kapancik S, Celik V K, Kilickap S, Kacan T, & Kapancik S. (2016) The Relationship of Agmatine Deficiency with the Lung Cancer. International Journal of Hematology and Oncology, 26(4), 103-109.

16. Piletz JE, Aricioglu F, Cheng JT, Fairbanks CA, Gilad VH, Haenisch B,Halaris A,Hong S, LeeJE,Li J, Liu P, Molderings GJ, Rodrigues ALS, Satriano J, Seong GJ, Wilcox G, Wu N, Gilad GM. (2013) Agmatine: clinical applications after 100 years in translation. Drug discovery today 18(17), 880-893.

17. Uzbay T. (2014) An alternative approach to understand schizophrenia: Polyamine hypothesis through NMDA receptors.

18. Çelik VK, Ersan EE, Kilicgun H, Kapancik S, & Ersan S. (2016) Agmatine mediated hypertonic stress development in Schizophrenia: a Novel study. Neuropsychiatry 6(5).

19. Morrison LD, & Kish SJ. (1995) Brain polyamine levels are altered in Alzheimer's disease. Neuroscience letters 197(1), 5-8.

20. Minois N, Carmona-Gutierrez D, & Madeo F. (2011) Polyamines in aging and disease. Aging (Albany NY) 3(8), 716-732.

21. Lewandowski NM, Ju S, Verbitsky M, Ross B, Geddie ML, Rockenstein E, Adame A, Muhammad A, Vonsattel JP, Ringe D, Cote L, Lindquist S, Masliah E, Petsko GA, Marder K, Clark LN, Small SA.(2010) Polyamine pathway contributes to the pathogenesis of Parkinson disease. Proceedings of the National Academy of Sciences, 107(39), 16970-16975.

22. Liu P, Collie ND. (2009) Behavioral effects of agmatine in naive rats are task- and delay-dependent. Neuroscience 163:82-96.

23. Lu W, Dong HJ, Gong ZH, Su RB, Li J. (2010) Agmatine inhibits morphine-induced memory impairment in the mouse step-down inhibitory avoidance task. Pharmacol Biochem Behav 97:256-61.

24. McKay BE, Lado WE, Martin LJ, Galic MA, Fournier NM. (2002) Learning and memory in agmatine-treated rats. Pharmacol Biochem Behav 72:551-7.

25. Zarifkar A, Choopani S, Ghasemi R, Naghdi N, Maghsoudi AH, Maghsoudi N, Rastegara K, Moosaviat M. (2010) Agmatine prevents LPS-induced spatial memory impairment and hippocampal apoptosis. Eur J Pharmacol 634:84-8.

26. Kim JH, Yenari MA, Giffard RG, Cho SW, Park KA, Lee JE. (2004) Agmatine reduces infarct area in a mouse model of transient focal cerebral ischemia and protects cultured neurons from ischemia-like injury. Exp Neurol 189:122-30.

27. Feng Y, Piletz JE, Leblanc MH. (2002) Agmatine suppresses nitric oxide production and attenuates hypoxic-ischemic brain injury in neonatal rats. Pediatr Res 52:606-11.

28. Takashi T, Katsuse O, and Iseki E. (2004) "Nitric oxide pathways in Alzheimer's disease and other neurodegenerative dementias." Neurological research 26.5: 563-566.

29. Gatto EM, Riobó NA, Carreras MC, Cherñavsky A, Rubio A, Satz ML, & Poderoso JJ. (2000) Overexpression of neutrophil neuronal nitric oxide synthase in Parkinson's disease. Nitric Oxide 4(5), 534-539.

30. Chinard FP. (1952). Photometric estimation of proline and ornithine. Journal of Biological Chemistry 199, 91-95.

31. Vivó M, de Vera N, Cortés R, Mengod G, Camón L, & Martínez E. (2001) Polyamines in the basal ganglia of human brain. Influence of aging and degenerative movement disorders. Neuroscience letters 304(1), 107-111.

253 32. Miller-Fleming L, Olin-Sandoval V, Campbell K, & Ralser M. (2015) Remaining mysteries of
254 molecular biology: the role of polyamines in the cell. Journal of molecular biology, 427(21), 3389-
255 3406.

256 33. Çelik VK, Kapancık S, Kaçan T, Kaçan SB, Kapancık S, & Kılıçgün H. (2017) Serum levels of
257 polyamine synthesis enzymes increase in diabetic patients with breast cancer. Endocrine
258 connections, 6(8), 574-579.

259 34. Sadasivudu B, Rao TI. (1976) Studies on functional and metabolic role of urea cycle
260 intermediates in brain. J. Neurochem 27(3), 785–794.

261 35. Pocklington AJ, Rees E, Walters JT, Han J2 Kavanagh DH, Chambert KD, Holmans P, Moran JL,
262 McCarroll SA, Kirov G, O'Donovan MC, Owen MJ. (2015) Novel Findings from CNVs Implicate
263 Inhibitory and Excitatory Signaling Complexes in Schizophrenia. Neuron 86(5), 1203-1214.

264 36. Glykys J, Mann EO, Mody I. (2008) Which GABAA Receptor Subunits Are Necessary for Tonic
265 Inhibition in the Hippocampus? J. Neurosci 28(6), 1421-1426.

266 37. Ginguay A, Cynober L, Curis E, & Nicolis I. (2017) Ornithine Aminotransferase, an Important
267 Glutamate-Metabolizing Enzyme at the Crossroads of Multiple Metabolic Pathways. Biology 6(1), 18.

268 38. Buée L, Hof PR, Bouras C, Delacourte A, Perl DP, Morrison JH, Fillit HM. (1994) Pathological
269 alterations of the cerebral microvasculature in Alzheimer's disease and related dementing disorders.
270 Acta Neuropathol 87: 469–480.

271 39. de la Torre JC, Mussivand T. (1993) Can disturbed brain microcirculation cause Alzheimer's
272 disease? Neurol Res 15: 146–153.

273 40. Mancardi GL, Perdelli F, Rivano C, Leonardi A, Bugiani O. (1980) Thickening of the basement
274 membrane of cortical capillaries in Alzheimer's disease. Acta Neuropathol 49: 79–83.

275 41. de la Torre JC, Stefano GB. (2000) Evidence that Alzheimer's disease is a microvascular
276 disorder: The role of constitutive nitric oxide. Brain Res Brain Res Rev 34: 119–136.

277 42. Stewart VC, Heales SJ. (2003) Nitric oxide-induced mitochondrial dysfunction: Implications
278 for neurodegeneration. Free Radic Biol Med 34: 287–303.

279 43. Albina JE, Mills CD, Henry WL Jr., Caldwell MD. (1990) Temporal expression of different
280 pathways of L-arginine metabolism in healing wounds. J Immunol. 144:3,877–80.

281 44. Hibbs JB, Vavrin Z, Taintor RR. (1987) L-arginine is required for expression of the activated
282 macrophage effector mechanism causing selective metabolic inhibition in target cells. J Immunol.
283 138:550–65.

284 45. Mills CD. (2001) Macrophage arginine metabolism to ornithine/urea or nitric oxide/citrulline:
285 A life or death issue. Crit Rev Immunol. 21:399–425.

286 46. Williams-Ashman HG, Canellakis ZN. (1979) Polyamines in mammalia biology and medicine.
287 Perspect Biol Med. 22:421–53.

288 47. Wu G, Morris SM. (1998) Arginine metabolism: nitric oxide and beyond. Biochem J. 336:1–
289 17.

290 48. Morris SM. (2007) Arginine Metabolism: Boundaries of Our Knowledge. J Nutr. 137:1, 602–9.

291 49. Kelly BL, & Ferreira A. (2006) β-amyloid-induced dynamin 1 degradation is mediated by N-
292 methyl-D-aspartate receptors in hippocampal neurons. Journal of Biological Chemistry, 281(38),
293 28079-28089.

294 50. Kabogo D, Rauw G, Amritraj A, Baker G, & Kar S. (2010) β-amyloid-related peptides
295 potentiate K+-evoked glutamate release from adult rat hippocampal slices. Neurobiology of aging,
296 31(7), 1164-1172.

297 51. Texidó L, Martín-Satué M, Alberdi E, Solsona C, & Matute C. (2011) Amyloid β peptide
298 oligomers directly activate NMDA receptors. Cell Calcium, 49(3), 184-190.

299 52. Auguet M, Viossat I, Marin JG, & Chabrier PE. (1995) Selective inhibition of inducible nitric
300 oxide synthase by agmatine. The Japanese Journal of Pharmacology 69(3), 285-287.

301 53. Satriano J, Schwartz D, Ishizuka S, Lortie MJ, Thomson SC, Gabbai F, Kelly CJ, Blantz, RC.
302 (2001) Suppression of inducible nitric oxide generation by agmatine aldehyde: beneficial effects in
303 sepsis. Journal of cellular physiology, 188(3), 313-320.

304 54. Mun CH, Lee WT, Park KA, & Lee JE. (2010) Regulation of endothelial nitric oxide synthase by
305 agmatine after transient global cerebral ischemia in rat brain. Anatomy & cell biology 43(3), 230-240.

306 55. Ahn SK, Hong S, Park YM, Choi JY, Lee WT, Park KA, & Lee JE. (2012) Protective effects of
307 agmatine on lipopolysaccharide-injured microglia and inducible nitric oxide synthase activity. Life
308 sciences 91(25), 1345-1350.

Table 1. The gender and age ranges of patients and control

	Alzheimer		Parkinson	
Gender	Control	Patient	Control	Patient
Male	25	25	19	19
Women	10	10	16	16
Age (X ± S)	77 ± 11	74 ± 14	67 ± 12	68 ± 11

Data expressed as mean ± standard deviation

Table 2. The serum Ornithine, Arginine Decarboxylase, Ornithine Decarboxylase and Agmatinase levels in patients and controls

	Alzheimer			Parkinson		
	Control	Patient	P	Control	Patient	P
ADC (pg/ml) (n=35)	3.07±0.22	3.08±0.13	>0.05	3.11± 0.21	3.07±0.22	>0.05
Agmatinase (pg/ml) (n=35)	3.06±0.21	3.02±0.21	>0.05	3.09±0.21	3.06±0.13	>0.05
ODC (pg/ml) (n=35)	3.13±0.15	3.11±0.23	>0.05	3.11±0.21	3.07±0.2	>0.05
Ornithine (µmol/ml) (n=35)	0.12±0.02	0.16±0.02	<0.05	0.14±0.03	0.16±0.02	**<0.05**

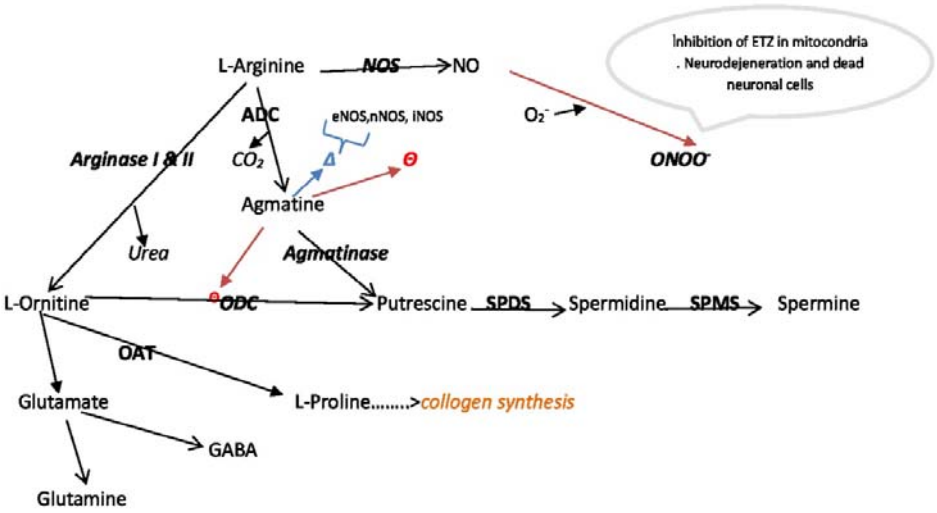

Figure 1: Regulation of NO synthesis and polyamines synthesis by agmatine. Nitric oxide synthase (NOS); endotelialNOS(eNOS); neural NOS(nNOS); inducible NOS (iNOS); Arginine decarboxylase (ADC); Ornithine decarboxylase (ODC); Spermidine synthase SPDS: Spermine synthase SPMS; γ-aminobutyric acid (GABA); Ornithine amino tranferase (OAT); Ornithine decarboxylase (ODC); inhibition; Θ; Activation Δ: