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Histomorphometric Findings on the Neocerebellar Purkinje Cells and Layer V Cerebral Pyramidal Cells Following Monosodium Glutamate Exposures

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Abstract: This study assessed some effects of monosodium glutamate which is one of the most abundant naturally occurring amino-acids that is frequently used as a seasoning material on histomorphometry on neocerebellar Purkinje and layer V neocerebral motor pyramidal cells in adult Wistar rats. **MATERIALS AND METHODS**: Forty-eight adult male Wistar rats weighing between 70-130g (8-10 weeks old) were randomly separated into four groups, each containing twelve rats. The rats in group A were regarded as the controls and they received only distilled water during the treatment period. The Wistar rats in group B, C and D received respectively 2g/kg, 4/kg and 6g/kg body weight of MSG orally once duty for 28 consecutive days. The rats were euthanized on 29th day and the whole brain and cerebellum were carefully excised, weighed and immediately fixed in 10% buffered formal saline for histological procedures for evaluation by light microscopy. **RESULTS:** The results of the total brain and cerebellar weights did not show any significant difference ($P > 0.05$) between the MSG – treated and control rats. However, there were significant differences ($P < 0.05$) in the relative total brain and relative cerebellar weights between the MSG – treated and control rats. Morphometric findings showed significant differences in the transverse diameters of neocerebellar Purkinje and layer V neocerebral pyramidal cells between the MSG – treated and control rats. The transverse diameters of Purkinje and pyramidal cells were significantly reduced ($P<0.05$) in MSG-treated rats compared with controls. Similarly, the neocerellar Purkinje cell and layer V pyramidal cell densities were significantly reduced ($P < 0.05$) in MSG – treated rats compared with controls. Additionally, the silver stained sections showed normal Purkinje and pyramidal cells with regular outlines and the processes penetrating the parenchyma in control sections while, the MSG-treated sections showed morphological evidence of neuronal loss and dead neurons. **CONCLUSION**: This study concluded that prolonged exposure to MSG may result in neocerebellar and layer V neocerebral cortical damage and neuronal degeneration and shrinkages that might be due to oxidative stress induced by neurotoxicity of MSG and consequently the motor cerebral and cerebellar functions might be compromised.

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INTRODUCTION

Monosodium glutamate ($C_5H_8NO_4N_aH_2O$) also known as sodium glutamate and MSG is a sodium salt of glutamic acid, a naturally occurring non-essential amino acid. Monosodium glutamate is one of the most abundant naturally occurring amino-acids frequently added as a flavour enhancing substance and additive in foods. Glutamate performs some functions in the body which include serving as an energy source for certain tissues and as a substrate for glutathione synthesis (Jehad, 2011). Some studies conducted on laboratory animals have shown the toxicity of monosodium glutamate in different organs, which manifested by increased oxidative stress and cytotoxicity that strongly correlated with numerous diseases, known as Chinese restaurant syndrome (Geha *et al*, 2000). The adverse effects of MSG in humans seem to manifest in MSG-sensitive individuals indicating that some people may have an MSG intolerance that causes MSG symptoms such as headache or migraine in some individuals.

It has been reported that MSG could induce hyperlipidemia; hyperglycemia and oxidative stress (Ahiuwalia *et al.*, 1996; Kuldip and Ahluwalia, 2005). Increased oxidative stress brings changes in the membrane lipids and proteins which could be responsible for some diseases (Kuldip and Ahluwalia, 2005).

Glutamate is the main excitatory neurotransmitter in the brain and the spinal cord and it is in higher concentration in the cerebral cortex, cerebellum and hippocampus (Sareesh *et al.*, 2010).

Glutamate receptors are present in the central nervous system as the major mediators of execratory neurotransmission and excitotoxity. Gill *et al* (2000) have reported that neural injury which is associated with trauma, epilepsy, stroke, and many neurodegenerative diseases such as Alzheimer’s, Parkinson’s and Huntington’s diseases may be mediated by excessive activation

of glutamate receptors. Modern nutrition is associated with a continuous intake of the flavour enchancer and accumulation of this substance with resultant rise of glutamic acid in the blood is a challenge and concern to the modern man (Walker and Lupien, 2000). This amino acid acts at multiple receptor types which consists of two main groups: ionotropic glutamate receptors (iGluR) and metatropic glutamate receptor {mGluR} (Hinol *et al* ., 2004).

Previous investigators have reported in several studies that the average consumption of MSG in Chinese adults is 3.6 grams upwards (He *et al*., 2008); however, findings from other studies have indicated the average value to be between 1 and 5 grams (Shi et al., 2010). This invariably makes MSG an important component of human diet

Previous investigators have reported a disruption in the levels biochemical parameters such as carbohydrates, proteins and lipids in MSG-treated rats (Ahluwalia and Malik, 1989). Chronic administration of MSG (4mg/g body weight and above) resulted in oxidative stress in experimental animals (Singh *et al.*, 2003; Diniz *et al.*, 2004).

The cerebellum is a region of the brain that plays an important role in the integration of sensory perception and motor output. The cerebellum contains nearly 50% of all neurons in the brain but it only takes up 20% of total brain volume and receives nearly 200 million input fibers.The basal ganglia and cerebellum are large collections of nuclei that modify movement on a minute-minute basis (Eweka and Eweka, 2011). The output of the cerebellum is excitatory, while the basic ganglia have inhibitory output. The balance between these two systems allows for smooth coordinated movement and a disturbance in either system will show up as movement disorders in termors, Nystagmus and Ataxia. The pyramidal cell (also called the principle cell) is the major excitatory neuron in all cortical layers except layer I, representing 70-85% of the total population of neurons in the mammalian cortex as well as well in the hippocampus (Sandrine *et al*., 2011).With few exceptions, pyramidal cell are the only projection neurons of the cerebral cortex (De Felipe and Farmas, 1992). In the light of the reported findings of the adverse effects of MSG on the body tissues, the present study reports the effects of oral exposure of high doses of MSG on the histomorphometry of the cerebellar Purkinje and cerebral motor pyramidal neurons in Wistar rats

MATERIALS AND METHODS

Animal Care

Forty-eight (48) male Wistar rats (8 and 10 weeks old) were used for the study. The rats were maintained in the Departmental Animal Holdings. They were housed in standard animal cages, fed with standard rat chow purchased from Global farms and drinking water was given to the Wistar rats *ad libitum*. The rats were maintained under standard laboratory conditions. The rats were given adequate care in accordance with the principles of laboratory and animal care (Institute of Laboratory Animal Resources 1996). All the Wistar rats were subjected to 2 weeks acclimatization period prior to treatment and body weights of the rats were monitored during this period using a sensitive weighing balance.

Chemicals

Ajinomoto which is one of the trade names of the concentrated forms of Monosodium Glutamate was procured from a grocery store in Waso market, Ogbomoso, Nigeria. The test material (MSG) was stored and protected from direct sunlight until the time of administration which was done orally using cannula.

Experimental Design

The 48 male Wistar rats weighing between 70g and 130g were randomized into four main groups, each containing 12 rats as follows:

Group A (n = 12) served as the normal control group, they received only distilled water and the Wistar rats in this group remained in their home cages throughout the experimental period.

Group B MSG- treated group (n = 12) was treated orally with aqueous solution of MSG (2g/kg) of body weight/day for 28 days).

Group C (n = 12) treated with 4g/kg MSG for 28 days.

Group D (n = 12) treated with 6g/kg MSG for 28 days.

The selection of the above doses was based on the previous reports by Sareesh *et al* (2010), Vinodini *et al* (2010) and Eweka *et al* (2007)

Animal Sacrifice and Collection of Brain Samples

The Wistar rats were euthanized on 29th day of the treatment the brain of each rat was immediately removed by dissection following the method of Abeer, (2009) weighed using a sensitive analytical weighing balance before fixing in 10% buffered formalin in accordance with previous investigators (Zhang *et al*., 2012; Mai,2013) for light microscopy using Hand E as described by Wilson and Gamble(2002). Silver stain for nerve cells and & their processes as described by Holme (2001).

Morphometric Analysis of the Neocerebellar Purkinje and Layer V NeoCerebral Pyramidal Cells

Quantitative analysis of the cerebellar Purkinje and layer V cerebral pyramidal cells was done on unedited photomicrographs taken form H and E

stained sections using Open Office software. Five non overlapping high power fields (X400) Soliman and Alshal (2009) were taken from each five serially sections of neocerebellar and layer V neocerebral cortical layers obtained from each group (A-D) in the study.

The number of Purkinje and pyramidal cells was counted in a calibrator (1272 x 1272mm) and the density (cell/mm^2) was calculated in each group. The transverse diameters of neocerebellar Purkinje cells and layer V neocerebral pyramidal cells were taken using the same software and the linear dimension was measured (mm).

Statistical analysis

Experimental data that were obtained from this study were expressed as Mean±SEM and compared across groups through analysis of variance (ANOVA) using GraphPad Prism for windows (Graphpad Prism software version 3 and tested for significance by the unpaired one-tailed student's t-test (Snedecor and Cochran, 1982).

RESULTS

Table 1 shows the mean ±SEM of total brain weights, cerebellar weights and their relative weights of controls and MSG- treated rats. The mean brain weight of controls (group A) was 1.619± 0.08 which was greater than 1.603±0.09 in group B, 1.596 ± 0.09 in group C and 1.604 ± 0.15 in group D. Similarly, the relative brain weight was 1.08%, 0.97%, 0.97% and 0.90% respectively in group A (control), B, C, and D treated rats. The mean brain weight decreased insignificantly (P> 0.05) in the MSG-treated rats. However, the relative brain weights decreased significantly (P< 0.05) in the MSG – treated rats compared with controls as shown in table 1.

Table 1 similarly shows that the mean cerebellar and relative cerebellar weights decreased insignificantly (P >0.05) in the MSG – treated rats compared with the controls. The mean ± SEM of cerebellar weight was 0.219 ± 0.03 in controls which decreased to 0.213 ± 0.01 in group B, 0.215 ± 0.03 in group C and 0.210 ± 0.03 in group D treated rats. The mean cerebellar weight decreased insignificantly (P> 0.05) in MSG-treated rats, while the relative cerebellar weight decreased significantly (P< 0.05) in a dose-dependent manner in group B (0.13), C (0.13) and D (0.12) compared with 0.15 in group A (Table 1).

Table 2 and Figure 1 show the cellular density of neocerebellar Purkinje cells (PCs) in various groups. The table demonstrated a dose-dependent decrease in the population of PCs in Wistar rats. The mean value was 7.20 ± 0.20/mm^2 in group A (Control) which decreased significantly to 4.00 ± 0.32/mm^2 in group B (MSG-treated), 3.00 ± 0.32/mm^2 in group C (MSG-treated) and 2.60 ± 0.51/mm^2 in group D (MSG-treated) rats. The PC population decreased significantly (P < 0.05) in the MSG-treated rats compared with controls.

Similarly, table 2 reveals a dose-dependent decrease in the transverse diameters of PCs. The transverse diameters of PCs decreased from 0.38 ± 0.01mm in group A (Control) to 0.26 ± 0.02, 0.23 ± 0.02, 0.20 ± 0.01 respectively in group B, C and D MSG-treated groups.

The transverse diameters were reduced significantly (P < 0.05) in MSG-treated groups compared with the control (Table 2 and Figure 2).

Table 1: Total Brain weight (g), relative brain weight (%), cerebellar weight (g), relative cerebellar weight of Wistar rats at the end of the treatment

Group	Mean ± SEM Total Brain Weight (g) A1	Relative Brain Weight (%)	Mean ± SEM Cerebellar Weight (g) A2	Relative Cerebellar Weight (%)
A (controls)	1.619 ± 0.08	1.08	0.219 ± 0.03	0.15
B (2g/kg MSG)	1.603 ± 0.09	0.97[a]	0.213 ± 0.01	0.13[a]
C (4g/kg MSG)	1.596 ± 0.09	0.97[a]	0.212 ± 0.03	0.13[a]
D (6g/kg MSG)	1.604 ± 0.15	0.90[a]	0.210 ± 0.03	0.12[a]

Data are represented as Mean ± SEM [a]Significant difference when compared with control using t- test at (P < 0.05).

Table 2: Showing the Mean ± SEM of Purkinje Cell Density (cells/mm^2) and the Corresponding Transverse Diameters (mm) in Neocerebellar Cortex Wistar Rats.

Group	Purkinje cell density (cells/mm^2)	Transverse diameters of Purkinje cells (μm)
A (Controls)	7.20 ± 0.20	0.38 ± 0.01
B (2g/kg MSG- Treated)	4.00 ± 0.32[a]	0.26 ± 0.02[a]
C (4g/kg MSG- Treated)	3.00 ± 0.32[a]	0.23 ± 0.02[a]
D (6g/kg MSG- Treated)	2.60 ± 0.51[a]	0.20 ± 0.01[a]

Data are represented as Mean ± SEM [a]Significant difference when compared with control (P < 0.05).

Table 3: Showing the Mean ± SEM of Pyramidal Cell Density (cells/mm^2) and the Transverse Diameters ((µm) in Layer V of Neocerebral Cortex of Adult Wistar rats.

Group	Pyramidal cell density (cells/mm^2)	Transverse diameters of Pyramidal (µm)
A (Control)	10.40 ± 1.60	0.21 ± 0.02
B (2g/kg MSG- Treated)	8.00 ± 1.05	0.17 ± 0.01
C (4g/kg MSG- Treated)	4.60 ± 0.51[a]	0.15 ± 0.00[a]
D (6g/kg MSG- Treated)	2.80 ± 0.38[a]	0.15 ± 0.01[a]

Data are represented as Mean ± SEM [a]Significant difference when compared with control (P< 0.05).

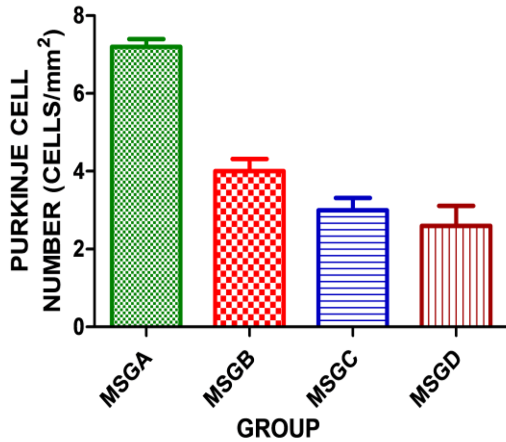

Figure 1: Showing the effects of MSG for 28 days on Purkinje cell density in neocerebellar cortex of adult Wistar rats. Each bar represents Mean± SEM

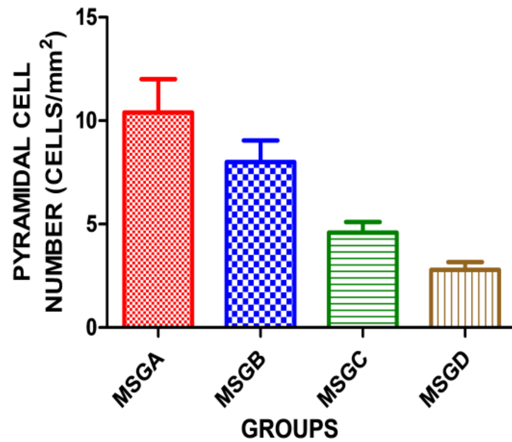

Figure 3: Showing the effects of MSG for 28 days on Pyramidal cell density in neocerebellar cortex of adult Wistar rats. Each bar represents Mean± SEM

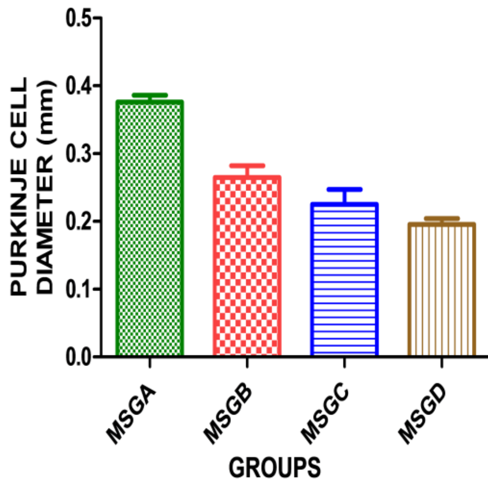

Figure 2: Showing the effects of MSG for 28 days on Purkinje cell diameter in neocerebellar cortex of adult Wistar rats. Each bar represents Mean± SEM

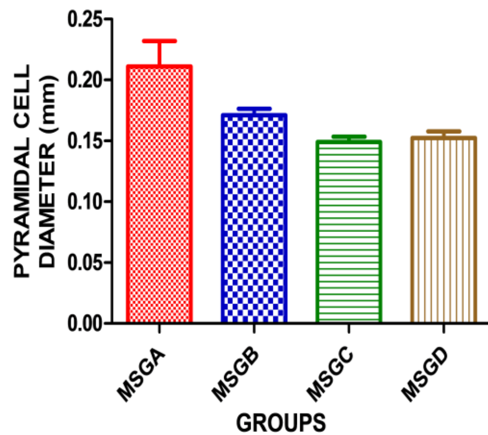

Figure 4: Showing the effects of MSG for 28 days on Pyramidal cell diameter in neocerebellar cortex of adult Wistar rats. Each bar represents Mean± SEM

Table 3 and Figure 3 also demonstrated a dose-dependent decrease in the density of large pyramidal cells in neocerebral cortex in the various experimental groups.

The mean value of pyramidal cell population was 10.40 ± 1.60/mm^2 in group A (Control) which decreased insignificantly to 8.00 ± 1.05/mm^2 in group B but decreased significantly (P < 0.05) to 4.60 ± 0.51/mm^2 in group C and 2.80 ± 0.38/mm^2 in group D MSG-treated groups.

The pyramidal cell population decreased insignificantly (P > 0.05) in group B but reductions became significant (P < 0.05) in group C and D MSG-treated groups compared with group A (control).

The transverse diameters of pyramidal cell were represented in table 3. The pattern of reductions in the transverse diameters of Pyramidal cells was consistent with the population of the pyramidal cells in various groups. The transverse diameters of layer Vpyramidal cells were insignificantly reduced

($P > 0.05$) in group B (MSG-treated) compared with group A (Control). However, the reductions in the transverse diameters of the pyramidal cells became significant ($P<0.05$) in group C and D (MSG-treated groups) compared with group A (Control). The mean transverse diameters in group A (Control) was 0.21 ± 0.02mm which decreased insignificantly to 0.17 ± 0.01mm in group B, 0.15 ± 0.00 mm in group C and 0.15 ± 0.01mm in MSG-treated
groups (Table 3 and Figure 4.).

DISCUSSION

Glutamic acid has been shown to be involved in a large number of neuronal processes and is believed to be an important factor in the pathogenesis of many central nervous system disorders such as cerebral hypoxia (Choi, 1988) neurodegenerative disease (Meldrum and Garthwaite, 1990, Schousboe et al, 1997 and epilepsy (Dingledine et al, 1990). The glutamate effect may be mediated by two types of receptors: ionotropic glutamate receptors which are multimeric proteins that function as ligand gated ion channels and metabotropic receptors that are coupled through G proteins to intracellular second messenger system (Krizbai et al, 1998).

The results on total brain and cerebellar weights did not show significant ($P > 0.05$) differences between the MSG-treated rats and controls. However, the differences became significant between the MSG-treated rats and controls when the relative total brain and relative cerebellar weights were considered. Previous investigators have reported that many neurotoxins have been implicated in reduced brain weight (Minnema, 1992; El-Sokkary et al, 2003). Brain damage has been associated with oxidative stress (Adebayo et al, 2009).Neurotoxins have been implicated in reduced brain weights by some investigators (Minnema, 1992, El-Sokkary et al, 2003). The significant reductions ($P < 0.05$) in the relative total brain and cerebellar weights in MSG treated rats in that study might be attributed to neurodegenerative and atrophic changes resulting in brain damage induced by increased lipid peroxidation leading to oxidative damage of the neocortical tissue in the MSG treated rats.

Cellular Quantification and Transverse Diameters of Pyramidal and Purkinje cells.

This study has shown considerable variations in the population and transverse diameters of the Purkinje and pyramidal cells following MSG administration. The Purkinje cell number decreased significantly ($P < 0.05$) in a dose-dependent manner in the MSG-treated rats compared with controls. Similarly, the pyramidal cell number decreased significantly ($P < 0.05$) in a dose-dependent manner in the MSG-treated rats compared with controls The Purkinje cell number decreased significantly ($P < 0.05$) in a dose-dependent manner in the MSG-treated rats compared with controls. The decrease may be due to neuronal degeneration that resulted in cell death and loss in MSG treated rats. The considerable loss in the Purkinje cells manifested in the treated neocerebellar sections as wide distances (increased gaps) between two Purkinje cells as seen in the photomicrographs of the treated sections. Previous investigation has indicated that extensive cell death in the central nervous system is present in all neurodegenerative disorders, added to this is the fact that neuronal degeneration has been implicated as causing extensive cell death in the central nervous system (Waters, 1994). Glutamate elicits neurotoxic effects through distinct receptors and non-receptor, mediated mechanisms (Zhang et al, 2012). Excessive stimulation of the three types of ionotropic glutamate receptors including NMDA; AMPA and Kainate receptors results in neuronal cell death by increasing Ca^{2+} and Na^{+} influx which invariably alters the normal cellular physiology (Choi, 1992). Furthermore, it has been reported that glutamate induces neuronal cell death in the central nervous system by excitotoxicity that is dependent upon the release of excitatory amino acid mainly glutamate (Zhang et al, 2012).

Exitotoxic cell death is partly due to excessive activation of NMDA type of ionotropic glutamate receptor and consequently excessive influx of Ca^{2+} occurs through the receptor, associated ion channel (Zhang et al, 2012) Glutamate is kept in specific vesicles and acts in about 30% of synapses in the central nervous system. It is released in small doses which binds to glutamate receptors and is then metabolized by specific enzymes (Choi and Rothan, 1990). Glutamate opens the receptor dependent channel and consequently a large quantity of calcium enters the cells which is highly toxic to the cells. It has been noted that the Ca^{2+} levels are stable and low around 10,000 times lower than the extracellular level under normal condition excess calcium stimulates a sequence of enzymatic reactions which mediate the oxidative cellular death (Gagliadi, 2000; Dawson et al, 2003). Other investigators have similarly reported that the transient overflow of Ca^{2+} which follows the abnormal stimulation of Glutamate receptors activate a number of intracellular mechanisms that are primary sources of ROS (Chan, 1996; Pellicciari, et al, 1998). Production of ROS invariably leads to a series of intracellular events like LPO, protein oxidation and protein cross-linking which result in cell death (Stadtman and Berlett, 1998). In addition, membrane peroxidation and membrane disintegration occurs when the concentrations of free radicals increase and exceed the normal levels which make the increased free radicals to bind the unsaturated bonds of fatty acids.

Increasing evidence has indicated that glutamate toxicity can be mediated by apoptosis and necrosis (Martin et al, 1990; Ankarcrona *et al*, 1995). Neurotoxins have been known to induce massive cell destruction observed in neurodegeneration as they have the tendency to trigger an apoptotic death pathway within the brain cells. Degeneration and loss of Purkinje cells observed in this study may be due to neurotoxic effects exerted by MSG in the treated groups. Previous investigation has noted that Purkinje cells are very sensitive to neurotoxin (Fonnum and Lock, 2000).

Apoptosis has been noted to play a key role in cell death that is observed in neurodegenerative diseases marked by a progressive loss of neurons as seen in Alzheimer's disease (Zhang and Bhavnani, 2005).

The exact cause of apoptosis is not fully understood, however, a number of factors such as free radicals, insufficient levels of nerve growth factors and excessive levels of glutamate have been implicated (Zhang and Bhavnani, 2005). A substantial body of evidence has suggested that glutamate toxicity involves oxidative stress and apoptosis (programme cell death).

The relationship between oxidative stress and apoptosis has been shown by previous investigators (Bluttke and Standstorm, 1994).

The role of glutamate receptors in the physiology and pathology of the Blood-Brain barrier (BBB) is not fully understood (Krizbal et al, 1998). However, breakdown of the barrier due to activation of the NMDA subsclass of glutamate receptors was proposed from previous investigation (Koenig et al, 1992). This assumption was substantiated by the report that glutamate in addition to NMDA receptor, induced an increased in the BBB permeability in rats (Mayhan and Didion, 1996; Miller et al, 1996). Additionally, further clarification has been made that the above glutamate effect may result from a direct action of glutamate on endothelial cells or from indirect effects on a neuronal or glial population in the vicinity of blood vessels (Krizbai et al, 1998). Necrotic cell death affects extensive cell populations and is characterized by cytoplasmic swellings, destruction of organelles and disruption of plasma membrane leading to inflammation and release of intracellular contents (Cinthya, 2004).

Conversely, apoptosis has been described as a distinct type of cell death that is characterized by cell shrinkage, blabbing of the plasma membrane, maintenance of organelle integrity, condensation and fragmentation of deoxyribonucleic acid (DNA), followed by ordered removal by phagocytosis (Wyllie et al, 1981). Additionally, apoptosis is triggered by a rise in cytoplasm Ca^{2+}, apoptotic calcium increase (ACT), apoptotic cell volume decrease (AVD) and changes in plasma lipid distribution (Schiegel and Williamson, 2000; Mariathasan, 2004) water loss, efflux of K^+ and Cl^- ions lead to AVD which characterize the early stage of apoptosis (Trimarchi et al, 2002).

The significant decreased the Purkinje cell and pyramidal cell number in the MSG-treated section observed in this study might be due to oxidative cellular death induced by neutoxic effects of MSG on the neuronal cells of the neocerebellar cortex in MSG-treated rats.

The transverse diameters of Purkinje and pyramidal cell in MSG-treated sections were significantly reduced compared with the controls. Report form previous work has demonstrated that cell death that occurs following neurodegeneration is induced by apoptosis or necrosis which differ morphologically biochemically and even physiological. Accidental or pathological cell death has been described as necrotic in nature which may be triggered by extrinsic insults to the cells and the effects may be traumatic, osmotic, toxic and thermal (Activation of caspase enzymes occurs as a controlled event through a genetic programme in response to cell death (Faber, 1981).

The mitochondria are essential organelles for aerobic life. Apoptotic proteins that exert their effects on the mitochondria affect them in various ways. They may cause mitochondrial swelling through the formation of membrane pores, or they may induce mitochondrial swelling through the formation of membrane pores or they may increase the mitochondrial membrane permeability which make the apoptotic effectors to leak out (Abass and El-Haleem). Consequently, mitochondrial proteins are released into the cytosol following an increase in mitochondrial permeability. They then bind to inhibitor of apoptosis proteins (IAP) and deactivates them thus preventing them from arresting the apoptotic process and invariably allowing apoptotic process to proceed. Suppression of the activity of a group of cysteine proteases called caspases by IAP also occurs which regulate the degradation of cells.

The actual enzymes involved in degradation, therefore, can be considered to be indirectly regulated by mitochondrial permeability (Fesik and Shi, 2001).

The large pyramidal cells in layer V of neocerebral cortex as well as Purkinje cells in neocerebellar cortex in MSG-treated rats appeared shrunken a form of apoptotic cell volume decrease (AVD) which made some pyramidal and Purkinje cells elongated because of the cell shrinkages that ultimately affected the transverse diameters of these neurons in MSG- treated rats.

The progressive reductions in large pyramidal and Purkinje cell transverse diameters in MSG-treated rats observed in this study may possibly be due to irreversible cell shrinkages in associated with apoptotic neuronal death of Purkinje and pyramidal cells induced by neurotoxicity of MSG in the

treated rats. Apoptotic cell death was demonstrated in this study which manifested as reduced pyramidal and Purkinje cell transverse diameters coupled with reduced cellular population of pyramidal and Purkinje cells in the MSG-treated rats.

This study concludes that MSG is excitotoxic to the brain, neocerebellar Purkinje and motor cerebral pyramidal cells in Wistar rats. These findings have untoward implications for the motor function of the cerebellar and cerebral motor cortices. Future studies in our laboratory will consider the distribution of the glutamatergic (NMDA, AMPA and kainate) receptors in the cerebellar and cerebral motor cortices in MSG-exposed rodents.

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