Effect of Sugammadex and Rocuronium Combination on Cranial Neurotoxicity in Rats: Experimental Study

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Abstract

Sugammadex is frequently used in clinical anesthetic practice. In order to determine whether sugammadex has neurotoxic effect, histopathological evaluation and antioxidant status of brain and cerebellum tissues were investigated. Thirty-two adult sprague dawley rats were divided into four groups. Purine Control Group (Group 1, n=8) had no action. The control group (Group 2, n=8) received 16 mg/kg serum physiologic, the sugammadex group (Group 3, n=8) received 16 mg/kg sugammadex and the sugammadex+rocuronium group (Group 4, n=8) received 16 mg/kg sugammadex and 1 mg/kg rocuronium. After drug administration, brain and cerebellum tissues were evaluated histological and biochemically for and oxidative damage. The overall structure of the brain and cerebellum tissues were normal in all groups. Images of the layers and the neurons contained there in were normal. No pathological findings were found. There had no statistically significant difference between the groups in terms of glutathione enzyme activity levels (GSH-Px) and the malondialdehyde (MDA) levels in rat brain. GSH-Px and MDA levels had a slight increase in sugammadex and sugammadex+rocuronium group in cerebellum tissues. These increases were statistically significant. But this increase did not cause any histopathological damage to the cerebellum tissue. The study demonstrates that sugammadex is safe for reversal of rocuronium effects in rats. Sugammadex in the dose ranges used in the studies, did not produce adverse effects in rats brain and cerebellum tissues.

Keywords: Rat, Neuromuscular Block, Sugammadex, Rocuronium, Brain tissues, Cerebellum tissues, Neurotoxicity

INTRODUCTION

In general anesthesia, muscle relaxant agents have used to facilitate surgical applications. Muscle relaxants are two types as depolarizing and non-depolarizing. Non-depolarizing muscle relaxants compete with acetylcholine (Ach) to bind to nicotinic receptors at the neuromuscular junction [1]. Rocuronium is the most commonly used steroid-building agent in non-depolarizing muscle relaxants. In order to regain the muscle functions of the patient and prevent residual neuromuscular block, it is necessary to remove the effect of the muscle relaxant agents temporarily [2,3].

Ratlarda Sugammadex ve Rocuronium Kombinasyonunun Kraniyal Nörotoksisiisite Üzerine Etkisi: DeneySEL Çalışma

ÖZ

Sugammadex klinik anestezi uygulamalarında sıkıla kullanılır. Sugammadexin nörotokskik etkiye sahip olup olmadığını belirlemek için, beyin ve serebellum dokularının histopatolojik değerlendirilmesi ve antioksidan durumu araştırıldı. Otuq ikii erişkin sprague dawley sıçanı dört gruba ayrıldı. Purin Kontrol Grubuna (Grup 1, n=8) işlem yapılmadı. Kontrol grubuna (Grup 2, n=8) 16 mg/kg serum fizyolojik verildi. Sugammadex grubuna (Grup 3, n=8) 16 mg/kg sugammadex ve sugammadex+rocuronium grubuna (Grup 4, n=8) 16 mg/kg sugammadex ve 1 mg/kg rokuronyum verildi. İlaç uygulamalarından sonra beyin ve beyincik dokuları histolojik ve oksidadif hasar açısından biyokimyasal olarak değerlendirildi. Beyin ve beyincik dokusunun genel yapısı tüm gruplarda normaldi. Katmanların ve içerdiği nöronların görüntüleri normaldi. Patolojik bulgu bulunulmadı. Gruplar arasında şanın beyninde glutatom enzim aktivite düzeyleri (GSH-Px) ve malondialdehid (MDA) düzeyleri arasında istatistiksel olarak anlamlı bir fark yoktu. Serebellum dokularında GSH-Px ve MDA düzeyleri sugammadex ve sugammadex+rocuronium grubunda haff bir artış gösterdi. Bu artışlar istatistiksel olarak anlamlıdı. Ancak bu artışı, beyincik dokusunda histopatolojik hasara neden olmadı. Çalışma, sugammadexin şançanlarında rocuronium etkisinin tersine çevrilmesinde güvenli olduğunu göstermektedir. Çalışma kullanılan doz aralıklarında sugammadexin şanın beyin ve beyincik dokularında olumsuz etki olumturmuştur.

Anahtar sözcükler: Rat, Nöromüsküler Blok, Sugammadex, Rocuronium, Brain tissues, Cerebellum tissues, Neurotoxicity

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reversal agents, such as neostigmine, implement their activity by raising the levels of Ach at the neuromuscular junction by competitive inhibition of Ach-esterase. Classic reversal agents may cause side effects owing to their nonselective potentiation of muscarinic Ach receptors [4]. Sugammadex is a recently developed γ-cyclodextrine, prepped to keep non-depolarising neuromuscular blocking agents. Sugammadex reverses the neuromuscular block of rocuronium. The agent does not bind to plasma proteins and biologically passive. It has no effectiveness on Ach-esterase or any receptor system in the body. Because of its ability to rapidly reverse neuromuscular block, reducing residual block formation and ensuring patient safety, it’s usage is increasing day by day [5]. In animal and human studies, it has been proved that sugammadex reverses the muscle relaxant effect of rocuronium. Although the safety and efficacy were reported in the studies, the side effects were not clearly demonstrated [6,7].

In general, oxidative stress is considered to be an early marker of neurological disease, and therefore, early oxidative stress detection is considered to be of great preventive value [8]. Drugs can cause free radical damage with their metabolites. Free oxygen radicals on cell membrane fatty acids initiate lipid peroxidation. Oxidation of polyunsaturated fatty acids result in aldehydes. Malondialdehyde (MDA) is the best known aldehyde. MDA causes cross-linking and polymerization of membrane components. MDA neutralizes receptors and membrane-bound enzymes in membranes. It can also cause serious damage to membrane proteins. The most known glutathione peroxidase (GSH-Px) in live tissues is amongst antioxidants. Antioxidants repaire oxidative damage and neutralize various reactive intermediates. Brain tissue is one of the most susceptible tissues of free radical-induced oxidative damage. MDA and GSH-Px are most commonly used to determine the oxidative damage caused by free radicals in tissues [8]. Although the penetration of sugammadex is minimal in the blood-brain barrier, studies have suggested that sugammadex may be neurotoxic [9]. Studies have shown that sugammadex activates mitochondria-dependent apoptosis. Depletion of neuronal cholesterol levels has been shown as a cause. Cholesterol homeostasis was associated with oxidative stress [10]. Therefore, we planned to study oxidative stress in brain and cerebellum tissue.

In this study it was evaluated neuropathological effects of sugammadex in rats by biochemical and histopathological methods. Additionally, this preclinical study compared the neurotoxic effects of sugammadex with sugammadex and rocuronium combination.

**MATERIAL and METHODS**

**Ethics Approval**

The study protocol was approved by the Local Ethics Committee for Animal Experiments of Adiyaman University, Turkey (Approval no: ADYU-HADYEK: 2018-2).

**Animals**

All experiments were conducted according to our National Institute of Health Guide for the Care and Use of Laboratory Animals [11]. The study was conducted in Experimental Animal Laboratory (Adiyaman, Turkey) in 2018. Thirty-two pieces, adult Sprague-Dawley male rats weighing 300-350 g were fed with standard pellet diet and water ad libitum. Room temperature (22-25°C) and humidity (50-55%) were monitored daily. Lighting was provided using cool white fluorescent lamps, with 12-h light and dark cycles (06.00-18.00).

**Experimental Groups**

The animals were divided into four groups (n=8).

**Group 1 (Purine Control Group):** The rats were consisted of animals with maintenance conditions in accordance with routine ethical rules that were not performed surgical treatment.

**Group 2 (Control Group):** The rats were given 16 mg/kg intravenous (IV) 0.9% isotonic saline.

**Group 3 (Sugammadex Group):** The rats were given 16 mg/kg IV Sugammadex (Bridion®, Schering-Plough Corporation, Oss, Netherlands).

**Group 4 (Sugammadex + Rocuronium Group):** The rats were given 1 mg/kg IV rocuronium (Esmeron®; Organon, Istanbul, Turkey) and three min later 16 mg/kg IV sugammadex (Bridion®; Schering-Plough Corporation, Oss, Netherlands).

All drugs were administered intravenously over the tail vein. Three days after the appropriate action, the brain and cerebellum tissues under ketamine/xylazine anesthesia wereatraumatically removed from the skull by dissection starting from the neck. Brain and cerebellum tissues were divided into interhemispheric incisions for biochemical and histological examinations.

**Biochemical Evaluation**

The removed brain and cerebellum tissue samples were washed with saline at a temperature of +4°C, were placed in ependorf tubes according to the cold chain principles and stored at -70°C until examined. In tissue samples, tissue homogenates for MDA and GSH-Px measurements were prepared in cold with 0.15 M KCl (10%, w/v) homogenizer.

Malondialdehyde; lipid peroxidation is an indirect indicator of the amount of free oxygen radical formed in the tissue. The tissue MDA concentration as a marker of lipid peroxidation is based on the method of Uchiyama [11] the supernatant extracted from the N-butanol phase of the pink colored product as a result of the MDA reacting with thiobarbituric
acid at 95°C was determined by spectrophotometer at 535 and 520 nm. Brain tissue was homogenized in 10% trichloroacetic acid and then centrifuged. After mixing the superficial liquid part with an equal volume of 0.67% thioubyric acid, it was incubated in boiling water for 15 min at 90°C, then cooled and centrifuged. The tissue MDA concentrations were measured in nmol/g tissue under 532 nm absorbance.

Glutathione peroxidase; GSH-Px catalyzes the reduction of harmful peroxides such as lipid peroxide and hydrogen peroxide. During this reduction, the reduced glutathione is converted into oxidized glutathione. GSH-Px analysis was performed according to the method described by Ellman \[14\]. Glutathione in the analysis tube reacted with 5-iodo-dithiobis-2-nitrobenzoic acid to give yellow-greenish color and the light intensity of this color was measured by spectrophotometer at a wavelength of 410 nm.

**Histological Analysis**

Other brain and cerebellum tissues were fixed with 10% formaldehyde at room temperature. Tissues were kept in this solution for ten days. After fixation, the tissues were washed in tap water to remove the fixation solution in the tissue. Then dehydration and polishing were performed according to routine histological tissue follow-up procedure. Finally, the completed tissues were made into paraffin blocks. 10 µm volume was calculated from the paraffin blocks with cavaliere method and 7 µm thick sections were taken for histological examination. For histopathological evaluation, sections were stained with cresyl violet (Merck, Cresyl violet acetate, FN 1107635, Germany). Cresyl violet staining is used in neurosciences to analyze neuron variations in various pathological cases. The images obtained by Carl Zeiss Axiocam ERC5 digital camera attachment microscope were examined and evaluated.

**Statistical Analysis**

The Statistical Package for the Social Sciences 22.0 program (SPSS Inc., Chicago, IL, USA) was used for the statistical study. The one sample Kolmogorov-Smirnov test was used to determine whether the data was distributed normally. One Way ANOVA test was used to analyze the MDA and GSH-Px values of the groups. Kruskal-wallis test was used for data not showing normal distribution and Dunnet test for multiple comparisons. Mann-Whitney U test was used to compare the groups. The results were reported as mean±standard deviation (SD). Results were assessed at a 95% confidence interval, and P value <0.05 was accepted as statistically significant.

**RESULTS**

As a result of the statistical measurements of the rat brain GSH-Px levels: 2022.35±430.02 nmol/g in the purine control group, 2067.22±391.34 nmol/g in the control group, 1917.39±469.98 nmol/g in the sugammadex group, and 2041.58±263.02 nmol/g in the sugammadex + rocuronium group, were found as wet tissue (Table 1). Compared study data; There was no statistically significant difference between the groups in terms of GSH-Px level (P=0.881). MDA, which is defined as an indicator of free radical damage in tissues, did not show a significant difference with sugammadex application compared to control groups. In the purine control group 995.36±121.03 nmol/g, in the control group 1012.95±119.70 nmol/g, 886.91±145.05 nmol/g in the sugammadex group and 1090.00±307.35 nmol/g in the sugammadex + rocuronium group. No significant difference was found in MDA levels in brain tissue (P=0.223).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Purine Control</th>
<th>Control</th>
<th>Sugammadex</th>
<th>Sugammadex + Rocuronium</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSH-Px (nmol/g)</td>
<td>2022.35±430.02</td>
<td>2067.22±391.34</td>
<td>1917.39±469.98</td>
<td>2041.58±263.02</td>
<td>0.881</td>
</tr>
<tr>
<td>MDA (nmol/g)</td>
<td>995.36±121.03</td>
<td>1012.95±119.70</td>
<td>886.91±145.05</td>
<td>1090.00±307.35</td>
<td>0.223</td>
</tr>
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As a result of the statistical measurements of the rat brain GSH-Px levels: 1770.76±74.33 nmol/g in the purine control group, 1785.18±157.27 nmol/g in the control group, 1669.8±126.07 nmol/g in the sugammadex group, and

**Table 1. Distribution of GSH-Px and MDA values in brain tissue of groups**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Purine Control (n=8)</th>
<th>Control (n=8)</th>
<th>Sugammadex (n=8)</th>
<th>Sugammadex + Rocuronium (n=8)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSH-Px (nmol/g)</td>
<td>1770.76±74.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1785.18±157.27&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1669.8±126.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1844.47±75.28&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.037*</td>
</tr>
<tr>
<td>MDA (nmol/g)</td>
<td>1086.65±118.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>945.95±195.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1363.86±375.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1342.09±334.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.013*</td>
</tr>
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</table>

<sup>a</sup> There is no statistically significant difference between the groups with the same letters and there is a statistically significant difference between the groups with different letters (P<0.05)
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1844.47±75.28 nmol/g in the sugammadex+rocuronium group were found as wet tissue (Table 2). Compared study data; There was statistically significant difference between the groups in terms of GSH-Px level (P=0.037). Increase of GSH-Px is significant in sugammadex and sugammadex+rocuronium group.

Malondialdehyde, which is defined as an indicator of free radical damage in tissues, showed a significant difference with sugammadex application compared to control groups (P=0.013). In the purine control group 1086.65±118.92 nmol/g, in the control group 945.95±195.60 nmol/g, 1363.86±375.21 nmol/g in the sugammadex group and 1342.09±3344.49 nmol/g in the sugammadex + rocuronium group. There was a slight increase in sugammadex and sugammadex rocuronium group. This increase was statistically significant. When examined with histo-pathological data, it was observed that the increases and decreases were at acute level. The free radical increase due to the increase in MDA did not cause any histopathological damage to the cerebellum tissue.

In the examined sections of the groups, the cortex was wrapped with a loose connective tissue piamater. The layers of the cerebral cortex could not be distinguished apart from the lamina molecule (Fig. 1-group 1a,1b,1c). The cells of the nerve tissue were distributed homogeneously to the entire cortex under the lamina molecule. The boundaries of the neurons were regular and the nuclei were prominent. Pyramidal neurons were also found between oval or rounded neurons. Cell extensions were prominent and smooth (Fig. 1-group 2a,2b,2c). The general

Fig 1. Histopathological evaluation of brain tissues
Light microscopic image of brain tissues belonging to group 1a, group 2a, group 3a and group 4a, respectively (x4, Krezil violet staining); Light microscopic image of group 1b, group 2b, group 3b and group 4b, respectively (x40, Krezil violet staining); Light microscopic image of hippocampus belonging to group 1c, group 2c, group 3c and group 4c, respectively (x40, Krezil Violet Coloring); ml; molecular layer; Black thick arrow; pyramidal neurons; Black fine arrow; neurons in the hippocampus; Black arrow head; neuroglial cells
structure of the hippocampus and neurons were normal. At the light microscopic examination, the pericardies of the neurons were well defined; pramidal. In addition, the nuclei of these cells were echromatic and distinctive nucleolus. Dendrites and axons, the extensions of the neurons, were of normal width. Neuroglia cells were also normal (Fig. 1-group 3a,3b,3c). The overall structure of the brain tissue was normal in all groups (Fig. 1-group 4a,4b,4c). Images of the layers and the neurons contained there were normal. No pathological findings were found.

The sections of the cerebellar cortex could be clearly distinguished in the sections examined. On the outermost side of the piamater-wrapped organ, the cortex was composed of lamina molecule, purkinje cell layer (ganglional layer) and granular layer from the outside (Fig. 2-group 1a,1b). The lamina molecule is a neuron-poor layer and the purkinje cells in the ganglional layer with the largest cells of the cerebellum were normal. In these cells, echromatic nucleus and a prominent nucleolus were seen. The dendrite from the top of the Purkinje cells was branched in the molecular layer. The granular layer was composed of multiple small diameter neurons (Fig. 2-group 2a,2b). The overall structure of the cerebellum was normal in all groups (Fig. 2-group 3a,3b; group 4a,4b). Images of the layers and the neurons contained there were normal. No pathological findings were found.

**DISCUSSION**

Cyclodextrins are chemical entities of natural origin, which are derived from bacterial. Sugammadex is a modified γ-cyclodextrin molecule. Only sugammadex received license for use in cyclodextrin molecules. Others did not pass drug phase tests. It has been understood that sugammadexin has a chemical interaction mechanism called encapsulation with neuromuscular agents [15]. Cyclodextrin molecules are employed to convert lipophilic agents to hydrophilic forms. Most cyclodextrins affect receptor functions by altering the lipid structure in the cell membrane. In one study, methyl-β-cyclodextrin has been reported to reduce neuronal excitability in the hippocampal area. Methyl β-cyclodextrin affects cholesterol levels in postsynaptic areas. N-methyl-D-aspartic acid receptor-dependent glutamate transmission may impair the transmission [16]. Neuroprotective effects have been demonstrated in studies with methyl-β-cyclodextrin and 2-hydroxypropyl-β-cyclodextrin [17,19]. A recently study was determined that sugammadex had a neuroprotective effect against transient cerebral ischemia. The study showed that treatment with 16 mg/kg and 100 mg/kg sugammadex had a neuroprotective effect in a transient cerebral ischemia/reperfusion injury rat model [20]. They reported that sugammadex had a protective effect against ischemia-reperfusion injury in brain. But a recent study showed that rocuronium has dose-related deleterious effects on the central nervous system and can produce dose-dependent excitatory effects and seizures [21]. Also it is known that rocuronium can permeate the CSF after intravenous injection [22].

Since sugammadex has a high molecular weight, it’s passage from the blood brain barrier (BBB) and placenta is low. But, in cases where cholesterol plugs are formed in the cerebral arteries and hypoxia occurs due to insufficient blood flow, tissue damage occurs and BBB structure is broken. In addition, in the case neurodegenerative diseases and traumatic brain or spinal cord injury BBB transition is easier [23]. Experimental studies have shown the neuroprotective characteristics of cyclodextrins, however the adverse effect of sugammadex on neuronal cell cultures has led to debate on this topic. The study showed that sugammadex causes apoptosis and neuron death in primary cell cultures. Sugammadex has been reported to induce apoptotic
activation by leading to oxidative stress and cholesterol hemostasis. Sugammadex reduced membrane-related cholesterol levels. They reported that they were sensitive to oxidative stress among neuronal cell types [11]. We took
cholesterol levels. They reported that they were sensitive
activation by leading to oxidative stress and cholesterol
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muscles [25]. Muscle relaxant rocuronium and antagonist
is responsible for the purposeful execution of voluntary
effect at the pathological level in the tissue. The cerebellum
were given sugammadex after rocuronium application.
It was determined the effects of sugammadex on the
histopathological and biochemical structure of rat brain
and cerebellum tissues after neuromuscular blockage. The
overall structure of the brain and cerebellum tissues were
normal in all groups. No pathological findings were found.
There was no statistically significant difference between
the groups in terms of glutathione enzyme activity
levels and the MDA levels in rat brain. MDA and GSH-Px
levels were altered in sugammadex and sugammadex
rocuronium group in cerebellum tissue. MDA and GSH-
levels remained at the acute level and did not show its
effect at the pathological level in the tissue. The cerebellum
is responsible for the purposeful execution of voluntary
movements. The information is transmitted directly to
the cerebellum via the proprioceptive receptors in the
muscles [25]. Muscle relaxant rocuronium and antagonist
sugammadex was effected to oxidative damage in
cerebellum. However, the effect was acute and transient
because it was not affected histopathologically. To the best
of our knowledge although there are studies on the brain,
its effect on the cerebellum has not been investigated.
We think that this study will shed light on new studies
in which the efficacy of the drug will be investigated.
This current study, sugammadex and sugammadex-
rocuronium applied in rats did not show any neurotoxic
effect. Sugammadex in the dose ranges used in the study,
did not produce adverse effects in animal study.

For clinicians, it is important to protect the patient’s brain
during surgery and in intensive care. For this purpose,
selection of suitable agents is required. The results obtained
in animal experiments provide reference to the use of
drugs in humans. The aim of this study was to determine
the effect of rocuronium and sugammadex on brain and
cerebellum tissues in rats. As a result, rocuronium and
sugammadex application had no negative effect on brain
cerebellum tissues. In our study, the neurotoxic effects
of the drugs were not observed. For the antagonism of
both peripheral and central long-term residual rocuronium
effects, it may be advisable to consider sugammadex.

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Not applicable.

CONFLICTS OF INTERESTS
The author declare no conflicts of interests.

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