

# **The neuroprotective effects of xenon on neonatal rats with white matter damage by regulating expression of microRNA-210 and HIF-1 $\alpha$**

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**Running title:** Xenon alleviates white matter damage

**Abstract:**

**Background:** Premature birth is a significant health care burden. White matter damage (WMD) is a leading cause of acute mortality and chronic morbidity in preterm birth. Xenon (Xe) is a general anesthetic with neuroprotective effects. We aimed to reveal the molecular basis and neuroprotective mechanism of Xe intervention in treating white matter damage by detecting the expression level of microRNA 210 (miR-210) and hypoxia inducible factor 1 $\alpha$  (HIF-1 $\alpha$ ) in brain tissues of 3-day-old neonatal rats.

**Methods:** Three-day-old SD rats were randomly divided into sham group (Group A, n=24), lipopolysaccharide (LPS) +hypoxia-ischemia (HI) group (Group B, n=24) and LPS+HI+Xe group (n=72). **LPS+HI+Xe group was given Xenon gas inhalation for three hours after treatment of HI at 0h,2h,and 5h,and divided into three subgroups C,D,and E randomly. We investigated the WMD by performing TUNEL and hematoxylin and eosin (HE) staining and examining the expression of miR-210and HIF-1 $\alpha$  in brain tissues via RT-PCR and western blot.**

**Results:** **Our study shows that the brain tissues of neonatal rat which stained by HE were pale, structure loosen, nerve fibers disordered, and**

psychosis along with apoptosis in group B, but Xe treatment improved the histological alterations and decreased the number of apoptotic cells in group C pups. The expression level of miR-210 increased significantly at all time points in group B when compared to group A ( $p < 0.05$ ), While that was significantly lower at 0h and 48h than that of group C ( $p < 0.05$ ), but made no difference with that of group D or group E ( $p > 0.05$ ). Compared with group C, the expression of miR-210 group D and group E decreased significantly at 0h, 24h and 48h ( $p < 0.05$ ). The expression level of HIF-1 $\alpha$  protein was statistically differentiated with each other at every time point ( $p < 0.05$ ). The level of HIF-1 $\alpha$  protein in group B was significantly higher than that of group A at each time point, while significantly lower than that of group C at each time point and that of group D and E at 0h, 24h and 72h ( $p < 0.05$ ). Compared with group C and group D, the expression level of HIF-1 $\alpha$  protein decreased significantly at 24h in group E ( $p < 0.05$ ).

**Conclusions:** These results demonstrate that the expression of HIF-1 $\alpha$  and miR-210 increased in periventricular tissues and Xe could relieve the white matter damage by up-regulating the expression of HIF-1 $\alpha$  and its target gene miR-210. The Xe therapeutic time window was within 5 hours after intervention, the sooner the better.

**Keywords:** premature birth, Xenon, microRNA-210, HIF-1 $\alpha$ , white matter damage

## Background

WMD is a prominent neurological deficit observed in preterm birth. WMD is a leading cause of acute mortality and chronic morbidity. [1] In a large cohort study, Hintz *et al.* previously reported that 19.3 % of the surviving preterm infants developed cerebella lesions. [2]The pathogenesis of WMD in premature birth primarily involves cerebral hypoxia-ischemia injury, systemic inflammation and maternal or fetal infection. [3, 4]To date, there are no available pharmacological agents that can efficiently attenuate the premature WMD, promote recovery or minimize the severity of disability.

Xe is a noble gas used in general anesthesia.[5]Xenon possesses organ-protective effects in the brain.[6, 7] Moreover, xenon exhibited neuroprotective activity for the treatment of ischemic brain injury in combination with mild hypothermia in animal models.[8-11] Xenon is known to cross the blood-brain barrier (BBB) and has a low blood/gas solubility, which will reduce the risk of developing adverse effects.[12-14]Previous reports demonstrated that the anesthetic effect of xenon was primarily mediated through the inhibition of N-methyl-D-aspartate (NMDA) receptor.[15,16] Particularly, Ma *et al.* demonstrated that xenon could induce the activation of hypoxia-inducible HIF-1 $\alpha$  and provide preconditioning effects on ischemic renal injury in mice.[17]However, the

exact molecular mechanism of xenon-mediated neuroprotection remains to be elucidated. Moreover, the neuroprotective effect of xenon in WMD has not been adequately investigated.

MicroRNAs (miRNAs) are endogenous, non-coding small RNA molecules of about 22 nucleotides in length and are involved in regulating gene expression, primarily at the posttranscriptional level. MiRNAs play a ubiquitous role in many vital biological processes, such as cell differentiation, proliferation, and apoptosis, etc. miR-210 is recognized as one of the most stable and significant microRNAs, and it is a stable target gene of HIF-1 $\alpha$ , during hypoxia, HIF-1 $\alpha$  is up-regulated, which induces the expression of microRNA-210 to increase. [18]In this study, we investigated the neuroprotective effects of xenon in a neonatal rodent model of WMD. Further, we examined the impact of xenon on the outcome through measuring the expression of HIF-1 $\alpha$  and miR-210 in neonatal brains.

## **Methods**

### ***Animals and Experimental groups***

Experiments were performed with 120 SD rat pups (the Experimental Animal Center of Qingdao, China), postnatal days 3 (P3) rat pups, weighing 7.5–11.3g, housed in temperature- and humidity-controlled cages with their

moms. Light was maintained in a 12-h light/dark cycle. All protocols were approved by the Institutional Animal Care and Use Committee of Qingdao University. All measures were taken to minimize animal discomfort.

Pups were randomly assigned into 3 different groups: sham-operated group (Group A, n=24), LPS + HI group (Group B, n=24), and LPS + HI + Xe (n=72). According to the onset of xenon treatment, the LPS+HI+Xe group was further divided into three subgroups, Group C (n=24), Group D(n=24) and Group E (n=24). which are separately delayed 0 hour, 2 hours, and 5 hours after HI.

### ***Induction of WMD and Xenon treatment***

Rat pups in Group B and Group C were first injected intraperitoneally (Ip) with LPS (*Escherichia coli* 0111:B4; Sigma, USA), while the Sham-operated pups (Group A) injected with normal saline (NS). To avoid LPS-induced body temperature changes, the rat pups were returned to their dams after LPS or NS injection, and housed in an incubator to maintain body temperature at 33 to 34°C before HI for 3 hours [19]. Next, pups were anesthetized with 5% chloral hydrate (0.01 ml/gm body weight, i.p) and HI was induced as described previously. [20]. briefly the right common carotid artery (CCA) was exposed, separated from nerves and veins and permanently ligated with

4-0 surgical silk. After the wound was sutured, the pups were allowed to return to the cages and recover from anesthesia. The entire surgical procedure never exceeded 5 minutes. Sham-operated pups underwent the same operative procedure except that the exposed carotid artery was not ligated. After surgery, the pups were returned to the cages. After 1-hour recovery, pups in Group B and Group C, D, E were placed in an airtight 3 L container partially submerged in a 36°C water bath, and exposed to humidify 8% oxygen (a mixture of 8% O<sub>2</sub> and 92% N<sub>2</sub>) with a flow rate of 3 L/minute for 1 hour. Following hypoxia, pups in Group B were returned to the cage until they were sacrificed. Group C, Group D, Group E were separately placed in a closed circuit container within 50% xenon (mixed with 30% oxygen and 20% nitrogen) for 3 hours[21]. The start of the 3 hours of xenon-treatment in Group C, Group D and Group E was separately delayed 0 hour, 2 hours, and 5 hours after HI. Carbon dioxide was removed from the container by soda lime pellets. The decapitation of rats was begun 0 hour, 24 hour, 48 hours and 72 hours after xenon treatment, and the rats in Group A and Group B were also decapitated at the same time with Group C. Animals were allowed to survive 3days, 4 days, 5 days and 6 days.

### ***Hematoxylin and eosin staining***

Brains were excised as described previously. [22] Briefly, pups were anesthetized with chloral hydrate and fixed on an operating panel. Next, the heart was exposed and a 10 ml syringe with 4% paraformaldehyde was inserted from the left ventricle to the aorta. Paraformaldehyde was injected into the heart until clear liquid flowed out from the atrium and the extremities became pale and stiff. Subsequently, the skull was systematically stripped to expose cerebral tissue. The periventricular brain tissue was dissected, immediately placed in 4% paraformaldehyde solution at room temperature for 48 hours, dehydrated in ethanol series, and embedded in paraffin. Paraffin blocks were coronally sectioned at a 10- $\mu$ m thickness from the genu of the corpus callosum to the end of the dorsal hippocampus. Hematoxylin and eosin (HE) staining was performed in four sections per brain. Stained sections were observed under a light microscope (OLYMPUS BX41, Olympus, and Center Valley, PA, USA).

### ***TUNEL staining***

Apoptosis was detected with terminal deoxynucleotidyl Transferase Biotin-dUTP Nick End Labeling assay (TUNEL, Roche) according to the manufacturer's protocol. Cells showing brown nuclei were considered as TUNEL positive cells and the average number of TUNEL positive cells from

5 randomly selected areas was counted under a light microscope (OLYMPUS BX41, Olympus, Center Valley, PA, USA).

### ***Western blot analysis***

Brain tissues were stored in aliquots at  $-80^{\circ}\text{C}$  until needed for further analysis. Western blotting was carried out to detect the levels of HIF-1 $\alpha$  in the white matter. The Brain tissue samples were homogenized in cold lysis buffer and the protein concentrations were determined using a BCA Protein Assay kit (Elabscience, Wuhan, China). Samples (40 $\mu\text{g}$ ) were separated using 10% SDS-PAGE and blotted onto polyvinylidene fluoride membranes overnight at  $4^{\circ}\text{C}$ . The membranes were incubated with primary antibodies including anti- HIF-1 $\alpha$  (1:500; Elabscience, Wuhan, China), and anti-GAPDH (1:1,000; Elabscience, Wuhan, China). After incubation, membranes were washed 5 times for 3 minutes. Proteins were visualized using anti-rabbit IgG antibodies which were conjugated to horseradish peroxidase (HRP)(1:50,000;Elabscience, Wuhan, China). Immunoreactivity was detected by horseradish-conjugated secondary antibodies and visualized by enhanced chemiluminescence. The band signals were quantified using an imaging software (BandScan 5.0).

### ***Real-Time Reverse Transcription-PCR***

Total RNA was extracted from brain tissue using Trizol (Aidlab, Lot:252250AX, Beijing, China) followed by quantification and reverse transcription using HiScript Reverse Transcriptase (RNase H) reagent Kit (Gene Copoeia, MD, USA) following the standard protocols. Next, real-time

PCR was performed using the 2×All-in-one tmqPCR Mix Kit (Vazyme Biotech, Nanjing, China). Then used specific miR-210 and an endogenous control U6 stem-loop primer, miR-210 or U6 stem-loop reverse transcriptase primers in a 20 µl system buffered with RT buffer and Distilled De-ionized Water (ddH<sub>2</sub>O). The RT thermal cycle program was as follows: 25 °C for 5 mins, 50 °C for 15 mins, 85 °C for 5 mins and 4 °C 10 mins. The resulting cDNA was stored at -20 °C. qPCR reaction (40 cycles) at 50 °C for 2 mins, at 95 °C for 10 mins, at 95 °C 30 s, and at 60 °C for 30 s. After amplification, the relative gene expressions were calculated in accordance with the  $\Delta\Delta C_t$  method. Relative miRNA levels were expressed as  $2^{-\Delta\Delta C_t}$  and ratios to control. Samples were analyzed in triplicates and the data from 6 RT-PCR samples were averaged.

### ***Statistical analysis***

All data were expressed as mean  $\pm$  SE. Statistical analysis was performed using IBM SPSS Statistics. The data conformed to normal distribution ( $P > 0.05$ ), and met the homogeneity of variance ( $P > 0.05$ ). Variance analysis was used and LSD was used to compare the two. Data didn't conform to normal distribution ( $P < 0.05$ ), or to normal distribution but didn't met the

homogeneity of variance, non-parametric test was used and two comparisons were made,  $p < 0.05$  was considered statistically significant.

## Results

### ***Protective effect of xenon following LPS and HI injury***

First, we examined the efficiency of LPS and HI in inducing WMD in P3 rat pups. In Group A (sham-operated), HE staining of brain tissue demonstrated a normal white matter structure and morphology, regular cell arrangement and a clear endoblast at 0, 24, 48 and 72 hours (Fig.1 A-D, respectively). Upon the induction of WMD, In Group B, regular cell arrangement almost disappeared, along with structure loosen, cellular swelling, nuclear membranes were unclear, cell nuclei showed pyknosis, and necrosis were detected (Fig.1E-H). The abnormal structure and morphology observed in the white matter following LPS and HI indicate that LPS-sensitized HI-induced WMD in group B pups. Following the 3-hour xenon inhalation, the pathological changes induced by LPS and HI were less prominent in group C compared to group B supporting the notion that xenon could protect against brain injury in premature rats at 0,24,48 and 72 hours(Fig1 I-L, respectively).

### ***Xenon alleviated the LPS and HI-induced apoptosis***

Next, we performed TUNEL staining to estimate the apoptosis at 24, 48 and 72 hours following LPS and HI treatment. In the sham-operated group (group A), TUNEL staining did not reveal significant apoptosis. In contrast, pups in group B showed a significant increase in apoptotic cells in the white matter at all examined time points (Fig.2 A-C). Further, the apoptosis rate was directly correlated with the survival period, i.e. the number of apoptotic cells significantly increased at 48h and peaked at 72 h following LPS and HI insult (Fig.2 G). Following xenon treatment in group C, the number of apoptotic cells significantly decreased at different time points compared to group B which is Xenon untreated ( $P < 0.05$  at 24, 48 and 72 hours, respectively. Fig.2 D-F and G).

### ***Xenon up-regulated the expression of miR-210 following white matter injury***

To investigate the effect of xenon treatment on the WMD, we detected the miR-210 level by RT-PCR. Compared to in group A, the expression level of miR-210 in neonatal rats' periventricular tissue increased significantly at all time points in group B ( $p < 0.05$ ). While the expression level of miR-210 in brain tissues of group B was significantly lower at 48h and 72h than that of group C ( $p < 0.05$ ), but made no difference with that of group D or group E

( $p > 0.05$ ). Compared with group C, the expression of miR-210 in brain tissues of group D decreased significantly at 24h and 72h ( $p < 0.05$ ), and group E decreased significantly at 0h, 24h, 48h and 72h ( $p < 0.05$ ). In addition, the expression of miR-210 at each group increased firstly and then decreased, and reached the peak at 48 hours. (Table 1 and Fig.3)

### ***Xenon up-regulated the expression of HIF-1 $\alpha$ after white matter injury***

Next, we investigated the expression of HIF-1 $\alpha$  and the efficiency of xenon treatment. Compared to in group A, Detection of HIF-1 $\alpha$  protein by Western blot, The expression level of HIF-1 $\alpha$  protein increased firstly and then decreased in each group, reaching peak at 24h, and was statistically differentiated with each other at every time point ( $p < 0.05$ ). The level of HIF-1 $\alpha$  protein in group B brain tissues was significantly higher than that of group A at each time point, while significantly lower than that of group C and D and E at 0h, 24h and 72h ( $p < 0.05$ ). Compared with group C and group D, the expression of HIF-1 $\alpha$  in the brain tissue of group E decreased significantly at 24h ( $p < 0.05$ ). (Table 2 and Fig.4)

### **Discussion**

The complex pathophysiology of WMD enables multiple targets at different time points of the disease process. For instance, **therapies are mainly concentrated on reduction of excitotoxic, oxidative and apoptotic mediators of injury in the early phase. Because of the severity of disability that may result, the development of therapies is important to reduce brain injury secondary to WMD.**

HIF-1 $\alpha$  is an important factor in the regulation of hypoxia, and has been proved involved in hypoxic-ischemic preconditioning in multiple species of tissues as a transcription factor. Physiologically, HIF-1 $\alpha$  is hydroxylated by prolyl-4-hydroxylases (PHDs) in the oxygen-dependent degradation domain of proline. After that, HIF-1 $\alpha$  becomes ubiquitin ligase complex, which is degraded by proteasome. Under normoxic conditions, HIF-1 $\alpha$  protein has a very short half-life (less than 5 min under posthypoxic conditions in cell culture), and decreases in oxygen concentration cause its stability to increase almost immediately, as reduction of PHD activity leading to degradation of proteasome. [23] HIF-1 $\alpha$  targets a wide variety of genes, including genes involved in energy metabolism, angiogenesis, cell proliferation, and survival. Among others, [24] and plays a role in hypoxic preconditioning in many organs by increasing the expression of HIF-1 $\alpha$ , [25,

26] especially in the brain, HIF-1 $\alpha$  plays an important role. Prass *et al.* [27] showed that hypoxia-induced HIF-1 $\alpha$  DNA connectivity increased, leading to cerebral ischemic tolerance. Hypoxic stimulation up-regulates the expression of HIF-1 $\alpha$  and EPO protein, produces reactive oxygen species, and plays an obvious neuroprotective role.[28] Recently, a number of microRNAs induced during hypoxia have been identified. Among of these microRNAs, miR-210 is strongly induced by HIF-1 $\alpha$  and has pleiotropic effects.[29] Fasanaro *et al.* reported that the expression level of miR-210 in endothelial cells was up-regulated in hypoxic environment, while promoting angiogenesis to a certain extent.[30] It is also closely related to hypoxic-ischemic diseases of the brain. Most studies have shown a direct link between the expression of miR-210 and hypoxia. [31-35] In particular, the expression of miR-210 was significantly up-regulated between normal and transformed cells, at the binding site of HIF-1 $\alpha$  on its promoter.[34] Some studies have shown that miR-210 plays an important role in cell survival, during hypoxia as a highly up-regulated microRNA.[29,30] Under normoxic conditions, the presence of miR-210 is not effective, but when hypoxia occurs, the increase of miR-210 expression will reduce the effect of hypoxic environment on cell metabolism to a minimum.[36] MiR-210 is a stable

target of HIF-1 $\alpha$ , which induces the up-regulation of the expression of miR-210 under hypoxic environment, [17]. Hypoxia can promote the expression of HIF-1 $\alpha$  increasing at 4 hours, peaking at 8 hours and decreasing at 24 hours, and apoptosis increases significantly at 24 hours after hypoxia, accompanied by down-regulation of HIF-1 $\alpha$  expression, that suggesting HIF-1 $\alpha$  may play a protective role in regulating apoptosis.[37] Animal experiments and cell culture data showed that the level of miR-210 increased immediately after hypoxic injury, and then decreased for several days. Along with ischemia and hypoxia, the level of HIF-1 $\alpha$  also changed continuously. Therefore, the level of miR-210 increasing after HI injury was regulated by HIF-1 $\alpha$  and related to the time of injury.[29,38] Kelly [39] recently discovered the loop of miR-210 regulating HIF-1 $\alpha$  and identified a new HIF-1 $\alpha$  regulatory factor, glycerol-3-phosphate dehydrogenase 1-like (GPD1L). The induction of miR-210 by HIF-1 $\alpha$  reduced the expression of GPD1L protein, thereby increasing the stability of HIF-1 $\alpha$ . In conclusion, HIF-1 $\alpha$  protein increased significantly in a certain period, peaked at 24 hours, and then gradually decreased to baseline level with the extension of time after HI injury in neonate rats. The protective effect was enhanced and then weakened. If intervention treatment was given after HI,

HIF-1 $\alpha$  degradation was inhibited to protect brain tissue, and the expression of miR-210 is related to the level of HIF-1 $\alpha$  protein, that will bring new ideas for the follow-up treatment of neonatal brain damage. Our data suggest that the expression levels of HIF-1 $\alpha$  protein and miR-210 in brain tissue increased after LPS combined with HI injury ( $p \leq 0.05$ ), which is consistent with the above study.

Xenon is an NMDA receptor antagonist that has been precluded from the widespread clinical use as a general anesthetic due to its relatively high cost.[14,15,40] Xenon has well documented neuroprotective properties that were reported in models of premature brain injury,[7,10,11,40]as shown in our previous papers.[41]In this study, we investigated the acute neuroprotective outcomes of xenon in an in vivo model of premature brain injury. In accordance with previous reports, we opted to use a 3-hour xenon treatment interval. [21,42] The present results indicate that xenon has the greatest neuroprotective effect in the range of 37.5-50 vol%, which is consistent with previous studies that 50% xenon can provide sufficient neuroprotective effect .[43-45] On the contrary, others have shown that xenon at 75% volume concentration has the greatest neuroprotective effect and does not affect oxygenation[43]. However, in addition to

neuroprotective effect, xenon at this concentration may have adverse side effects .[45] We choose a mixture of 50% xenon, 30% oxygen and 20% nitrogen to intervene, the mixture has  $2.8\times$  the density but almost the same viscosity as air .[46]In our study, following LPS and HI insult, we observed the expression of miR-210 and HIF-1 $\alpha$  elevated, and our results revealed that the administration of 50% xenon balanced with 30% oxygen and 20% nitrogen for 3 hours after injury resulted in a significant increase of miR-210 and HIF-1 $\alpha$  ( $p<0.05$ ). These results suggest that xenon can alleviate white matter damage by activating HIF-1 $\alpha$  expression, and the stable expression of HIF-1 $\alpha$  can regulate the expression of microRNA-210, which plays a neuroprotective role by inhibiting neuronal apoptosis through related pathways. The available time-window for treatment effectiveness and administration is an important aspect to consider in potential treatments for premature brain injury. Therefore, we investigated the effectiveness of xenon when administered immediately or delayed for 2 or 5 hours following LPS and HI-induced injury. The level of microRNA-210 did not increase significantly, but the level of HIF-1 $\alpha$  protein did not decrease significantly. Maintaining and stabilizing the level of HIF-1 $\alpha$  protein still served to protect brain tissue. In addition, results revealed that the delay in

xenon administration for 5 hours resulted in a significant increase of HIF-1 $\alpha$  ( $p>0.05$ ), which may suggest that xenon still exerts its neuroprotective effects for up to 5 hours after injury, and the regulation between HIF-1 $\alpha$  and microRNA-210 is related to the time of injury, and may suggest that xenon still exerts its neuroprotective effects for up to 5 hours after injury, the sooner the better.

In summary, we showed that xenon is an efficient neuroprotective agent against premature brain injury in a rodent model of WMD. Our results indicated that xenon treatment up regulated the expression of miR-210 and HIF-1 $\alpha$  and improved neurological outcome after WMD. The therapeutic time-window of xenon extends for up to 5 hours. Our findings are in agreement with the previously demonstrated neuroprotective effects of xenon in HI injury.[7,41] The duration of xenon treatment was relatively short (3 hours) which might suggest that the extension of treatment time might result in better neuroprotection and a longer therapeutic time window. Our findings support the idea that xenon could provide a first-line treatment for white matter injury in premature infants. The development of xenon-closed circuit delivery system and advances in gas extraction technology will potentially lead to enhanced procedures of xenon dosing

with reduced cost.[47] Further, xenon is a non-flammable gas that can be easily administered at the bedside. In conclusion, the present study revealed a novel effect of xenon in protection against premature brain injury. Future experimental studies and clinical trials would be valuable in providing further insights into xenon neuroprotective efficacy.

### **Conclusions**

In conclusion, our data indicate that the expression of HIF-1 $\alpha$  and miR-210 increased in periventricular tissues and Xe could relieve the white matter damage by up-regulating the expression of HIF-1 $\alpha$  and its target gene miR-210. The Xe therapeutic time window was within 5 hours after intervention, the sooner the better.

### **Abbreviations**

BBB: blood-brain barrier; CCA: Common carotid artery; GPD1L: Glycerol-3-phosphate dehydrogenase 1-like; HE: Hematoxylin and eosin; HI: Hypoxia-ischemia; HIF-1 $\alpha$ : hypoxia inducible factor 1 $\alpha$ ; LPS: lipopolysaccharide; miR-210: microRNA 210; miRNAs : MicroRNAs ; NMDA: N-methyl-D-aspartate ; PHDs : Prolyl-4-hydroxylases; WMD : White matter damage;

Xe: Xenon

### **Declarations**

**Ethics approval and consent to participate**

The protocols, which include all surgical procedures and animal usage, were approved by the Institutional Animal Care and Use Committee of Qingdao University, and conformed to the Guide for the Care and Use of Laboratory Animals by the National Institutes of Health.

**Consent for publication**

Not applicable

**Availability of data and material**

The data and analysis in this study could be reasonably acquired from the corresponding author.

We use the same animals as a source of samples for the studies outlined in this manuscript (Impact of Xenon on CLIC4 and Bcl-2 Expression in Lipopolysaccharide and Hypoxia-Ischemia-Induced Periventricular White Matter Damage, DOI: [10.1159/000487220](https://doi.org/10.1159/000487220))

**Competing interests**

None declared

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### **Authors' contributions**

YXY, ZJX, JH had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept, design, and drafting of the article: YXY, ZJX, LXH Acquisition, analysis, and interpretation of data. Animal experiment: JJ, XHM, ZLL. All authors have read and approved the manuscript.

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## Figure legends

**Figure 1.** Representative hematoxylin and eosin-stained coronal brain sections from postnatal day 3 SD rat pups. (A-D) a normal white matter structure and morphology, regular cell arrangement in the sham-operated pups (group A) at 0, 24, 48 and 72 hours, respectively (n=6). (E-H) Distorted cytoarchitecture, nuclear psychosis (white arrows), and cellular swelling (black arrows) observed in the brain sections observed in the brain sections following LPS and HI in group B at 48 and 72 hours, (n=6). (I-L) Protective effect of xenon in group C pups at 0, 24, 48 and 72 hours, (n=6). Scale bar=50  $\mu$ m in B-D, F, H-L; Scale bar=100  $\mu$ m in A, E and G.

**Figure 2.** Representative images of TUNEL staining from postnatal day 3 SD rat pups. (A-C) Following LPS and HI the number of apoptotic cells increased significantly in group B pups at 24, 48 and 72 hours (n=3). (D-F) Protective effect of xenon in group C pups at 24, 48 and 72 hours, (n=3). G Bar chart representing the average number of TUNEL positive cells of group B and group C, \* $p < 0.05$  compared to group B.

**Figure 3.** Expression of miR-210 in the brain tissue at different time points in group A-E. A: Bar charts representing the relative expression of miR-210 at 0, 24, 48 and 72 hours in group A and B, #  $p < 0.05$  compared to group A (n=6). B: Bar charts representing the relative expression of miR-210 in groups B, C, D and E at 0, 24, 48 and 72 hours. \*  $p < 0.05$  compared to group B (n=6),  $\Delta p < 0.05$  compared to group C (n=6)

**Figure 4.** The expression of HIF-1 $\alpha$  in the brain tissue at different time points in groups A -E .**A** Western blot analysis of HIF-1 $\alpha$  expression at 0 h among the different groups, and bar chart representing the quantitative analysis of HIF-1 $\alpha$  expression level normalized to GAPDH level, #  $p < 0.05$  compared to group A,  $\blacktriangle p < 0.05$  compared to group B (n = 6). **B** Western blot analysis of HIF-1 $\alpha$  expression among the different groups at 24 h ,and bar chart representing the quantitative analysis of HIF-1 $\alpha$  expression level normalized to GAPDH level, #  $p < 0.05$  compared to group A  $\blacktriangle p < 0.05$  compared to group B,\*  $p < 0.05$  compared to group C,  $\triangle p < 0.05$  compared to group D (n = 6). **C** HIF-1 $\alpha$  expression among the different groups at 48 h, and bar chart representing the quantitative analysis of HIF-1 $\alpha$  expression level normalized to GAPDH level, #  $p < 0.05$  compared to group A,  $\blacktriangle p < 0.05$  compared to group B (n = 6).**D** HIF-1 $\alpha$  expression among the different groups at 72 h, and bar chart representing the quantitative analysis of HIF-1 $\alpha$  expression level normalized to GAPDH level, #  $p < 0.05$  compared to group A,  $\blacktriangle p < 0.05$  compared to group B (n = 6).

<b>Time</b>	<b>Group A</b>	<b>Group B</b>	<b>Group C</b>	<b>Group D</b>	<b>Group E</b>	<b>F</b>	<b>P</b>
<b>0 h</b>	1.1777±0.1	2.1105±0.7	3.2123±0.80	2.1400±0.20	1.5578±0.37	12.04	0.00
	033	881 <sup>#</sup>	98	77	74 <sup>Δ</sup>	4	0
<b>24 h</b>	1.2943±0.2	2.7547±0.8	3.5862±0.69	2.4792±1.20	1.8092±0.49	8.035	0.00
	501	061 <sup>#</sup>	91	63 <sup>Δ</sup>	65 <sup>Δ</sup>		0
<b>48 h</b>	1.2943±0.2	3.6247±1.1	7.3270±2.18	3.7732±2.76	2.2940±1.25	10.21	0.00
	501	523 <sup>#</sup>	08 <sup>*</sup>	45	60 <sup>Δ</sup>	2	0
<b>72 h</b>	1.1777±0.1	1.9407±0.5	2.6175±0.18	1.7612±0.92	1.9000±0.36	5.982	0.00
	033	469 <sup>#</sup>	98 <sup>*</sup>	02 <sup>Δ</sup>	14 <sup>Δ</sup>		2

Table 1. Expression of miR-210 (as means ± SE) in the brain tissue at different time points in group A-E

Table 2. The expression of HIF-1 $\alpha$  (as means  $\pm$  SE) in the brain tissue at different time points in

Tim	Group A	Group B	Group C	Group D	Group E	F	<i>p</i>	groups A -E
<b>0h</b>	0.2273 $\pm$ 0.0	0.3435 $\pm$ 0.01	0.4578 $\pm$ 0.049	0.4428 $\pm$ 0.043	0.4225 $\pm$ 0.032	26.29	0.00	
<b>24</b>	0.2448 $\pm$ 0.0	0.5173 $\pm$ 0.03	0.6582 $\pm$ 0.035	0.6167 $\pm$ 0.036	0.5667 $\pm$ 0.537 <sup>▲</sup>	95.55	0.00	
<b>48</b>	0.2557 $\pm$ 0.0	0.4175 $\pm$ 0.05	0.5080 $\pm$ 0.070	0.4597 $\pm$ 0.059	0.4747 $\pm$ 0.031	15.99	0.00	
<b>72</b>	0.2617 $\pm$ 0.0	0.3745 $\pm$ 0.02	0.4330 $\pm$ 0.037	0.4273 $\pm$ 0.020	0.4297 $\pm$ 0.016	43.33	0.00	