Original article

Lavender oil (*Lavandula angustifolia*) attenuates renal ischemia/reperfusion injury in rats through suppression of inflammation, oxidative stress and apoptosis

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ABSTRACT

Renal ischemia/reperfusion (I/R) injury following kidney transplantation has been found to be a great clinical problem owing to initiation of acute inflammatory responses and subsequently rapid loss of kidney function. It is well known that lavender oil exhibits an extensive spectrum of pharmacological and biochemical activities. The purpose of this study was to clarify molecular targets of lavender in treatment of this disease.

Male Wistar rats weighing 200–250 g were divided into three major groups: sham, I/R, and I/R + different doses of lavender oil (L1:50 mg/kg, L2: 100 mg/kg, and L3: 200 mg/kg). A rat model of renal I/R (45 min ischemia and 24 h reperfusion) was created and lavender was administrated at 1 h after the beginning of reperfusion (i.p). Activities of antioxidant enzymes such as SOD, GPX, and CAT, and lipid peroxidation were evaluated. The expression of inflammatory cytokines such as TNFα, IL1β, and IL10 was determined by IHC and ELISA assay. Apoptosis activity and tissue damage were evaluated by TUNEL and H & E staining, respectively.

Our results showed that lavender oil markedly restored activities of antioxidant enzymes and reduced lipid peroxidation (P < 0.05). Lavender significantly decreased levels of TNFα and IL1β and increased level of IL10 in a dose-dependent manner (P < 0.05). Lavender reduced TUNEL positive cells in a dose-dependent manner. However, lavender reduced damage to peritubular capillaries and contributed to preservation of normal morphology of renal cells.

In sum, our findings establish a fundamental foundation for future drug industry to decrease the rates of rejection in kidney transplant patients.

1. Introduction

Renal ischemia/reperfusion (I/R) is a potential serious threat after kidney transplantation which leads to graft dysfunction, and high morbidity and mortality rate in early stages [1,2]. One of the core manifestations of this complex syndrome is acute kidney injury that occurs owing to rapid loss of kidney function by acute inflammatory responses [3,4]. Additionally, after ischemia, reperfusion triggers a pathophysiological cascades including burst release of intracellular Ca^{2+} ion, excessive generation of free radicals and ROS, neutrophil recruitment which, in turn, accelerate inflammation, sustained local ischemia and cellular damage [5–8]. It has been reported that different cellular signaling pathways are involved in I/R injury and other disorders [9–13]. Among them, oxidative stress and inflammation play a pivotal role in acute renal ischemia [14]. In fact, excessive production of ROS leads to formation of a cytotoxic metabolite, peroxynitrite, which can initiate multiple and irreversible consequences such as oxidative DNA damage, necrotic and apoptotic cell death, and destruction of membrane lipids owing to lipid peroxidation [15]. During lipid peroxidation, abstraction of a hydrogen atom gives rise to lipid radical

generation/propagation and subsequently formation of some breakdown products. Inflammation is a common abnormality in renal I/R and displays a powerful role in its pathophysiology. Chemokines mainly modulate the inflammation and subsequently secretion of pro-inflammatory cytokines, activation and infiltration of leukocyte, and expression of adhesion molecules. Pro-inflammatory cytokines such as IL1β and TNFα are master mediators of renal dysfunction and damage after I/R injury [16]. Therefore, inhibition of inflammatory responses can be an efficient approach to reduce injury after reperfusion. Although researchers have used many novel pharmacological agents and methods in the laboratory to improve renal I/R and other diseases, only a few of these agents or approaches have been translated to routine clinical use [17–20]. Lavender, a flowering plant in the Labiatae (Lamiacae) family, is widely used in traditional medicine for centuries as a herbal remedy [21]. There are four main categories for lavender: *Lavandula latifolia, Lavandula stoechas, Lavandula angustifolia,* and *Lavandula x intermedia* [22]. Lavender can act as antispasmodic, anticonvulsant, antidepressant, pain killer and carminative to treat various diseases [23–25]. A recent study reported that the main constituent of essential lavender oil was 1, 5-Dimethyl-1-vinyl-4-hexenyl butyrate. However, the authors observed high antioxidant activity of essential lavender oil against lipid peroxidation [26]. Currently, it has been reported that lavender oil can reduce focal cerebral injury by targeting apoptosis [27]. Additionally, it has been reported that lavender oil can accelerate burn healing through modulating the balance of pro-inflammation and anti-inflammation cytokines [28]. On the basis of the aforementioned studies, we went on to evaluate the protective effect of lavender oil against renal I/R injury that has not been done so far. We demonstrated that lavender oil exerts protective effects against renal I/R injury by targeting pro-inflammatory and anti-inflammatory cytokines, oxidative stress and apoptosis.

2. Materials and methods

2.1. Materials and chemicals

Natural Lavender oil from *Lavandula angustifolia* L and in situ Cell Death Detection Kit were purchased from sigma chemical company. Anti-TNF alpha antibody (ab6671, 1/200), Anti-IL1 beta antibody (ab9722, 1/200), Anti-IL10 antibody (ab9969, 1/200) were obtained from abcam company. Goat anti-rabbit IgG-FITC secondary antibody was supplied by Santa Cruz Biotechnology's company. Rat TNFα ELISA Kit, Rat IL-1β ELISA Kit, and Rat IL-10 ELISA Kit were purchased from MyBioSource Company (San Diego, USA).

2.2. Animals and ethical statement

Male Wistar rats (200–250 g) were purchased from Animal Center of Iran University of Medical Sciences. The animals were placed in a room that the temperature (22 ± 2 °C) and humidity (62–65%) were maintained constantly and under a 12 h light and dark schedule. The animals were fed with standard chow pellet and continuous access to water. Prior to the experimental tests, School of Medicine Animal Care and Use Committee of Iran University of Medical Sciences approved all the protocols.

2.3. Experimental design

The animals were randomized into three major groups: a group of animals received all surgical procedures except occlusion of renal artery (sham group; n = 10); a group of rats were only endured occlusion of renal artery for 45 min and reperfusion for 24 h (I/R group; n = 10); three subgroups of the animals were subjected to occlusion of renal artery and treated with different doses of lavender oil (L1, 50 mg/kg; L2, 100 mg/kg; L3, 200 mg/kg body weight). In the case of treatment subgroups, different doses of lavender oil were intraperitoneally

administrated at 1 h after the beginning of reperfusion.

2.4. Surgical procedure

In brief, the animals were anesthetized with a mixture of ketamine (50 mg/kg) and xylazine (7.5 mg/kg).To keep core body temperature at 37 °C, the animals were placed on a homoeothermic table. The right nephrectomy was carried out through a midline incision in upper abdominal region. After 21 days, the animals were anesthetized again and ischemia was induced through occlusion of the left renal pedicle. The color changing of the kidney surface approved renal artery occlusion. Humid and sterilized gauze was used to preserve kidney during 45 min ischemia. After 45 min ischemia, the occlusion clip was released to permit recirculation of blood flow for 24 h. At 24 h after reperfusion, the animals were killed under deep anesthesia to collect tissue samples for biochemical assessment including oxidative stress makers, and inflammatory cytokines.

2.5. Homogenization of tissues

At 24 h after reperfusion, the kidney tissues were rapidly dissected and removed from the body on ice. The kidneys were washed with cold saline solution and were weighed. Then, 150 mg of the tissue was divided and was homogenized within 1.5 mL phosphate buffer using a homogenizer (IKA T18, Basic ULTRA TURRAX, USA) at 5000 rpm for 3 min. In the next step, resulting solution was centrifuged. To decrease the destruction of enzymes, all the mentioned above steps were performed at 4 °C. After centrifuging, supernatant was separated and was applied to determine oxidative stress markers and inflammation-associated cytokines.

2.6. Assessment of CAT activity

A calorimetrically enzymatic assay kit at 405 nm (ZellBio GmbH, Ulm, Germany) was used to measure CAT activity. The amount of the sample that contributes to decomposition of 1 μmole of H_2O_2 to water and O_2 in one minute is considered as the CAT activity unit. The sensitivity of this assay is about 0.5 U/mL.

2.7. Assessment of GPX activity

The Cayman Chemical Glutathione Peroxidase Assay Kit at 340 nm (Cayman Chem, Ann Arbor, MI, USA) was used to determine GPX activity. In this assay, measurement of GPX activity is based on a decrease in absorbance at 340 nm owing to the oxidation of NADPH to $NADP^+$. GPX activity is expressed as U/mL.

2.8. Assessment of SOD activity

The measurement of SOD activity was performed using the Cayman Chemical SOD Assay Kit (Cayman Chem, Ann Arbor, MI, USA) pursuant to the manufacturer's instructions. In this assay, the measurement of SOD activity is based on measuring the dismutation of superoxide radicals generated by xanthine oxidase and hypoxanthine. The sensitivity of this assay is about 0.005 U/ml.

2.9. Assessment of MDA

MDA level was measured using a commercial chemical colorimetrical assay kit pursuant to the manufacturer's instructions (ZellBio GmbH, Ulm, Germany). In this assay, the reaction of MDA and TBA under high temperature results in formation of the MDA-TBA adducts. MDA level was determined in acidic media and heat (90–100 °C) colorimetrically at 532 (530–540 nm). The sensitivity of this assay is about 0.1 μM.

2.10. Renal function

To evaluate renal function, serum BUN and Crlevels were measured. At 24 h after reperfusion, blood samples were collected, centrifuged, and kept at 20 °C prior to assessments. Serum levels of BUN and Cr were determined by spectrophotometry using a commercial kit (Abbott Laboratories) and an Architect c16000 Autoanalyzer (Abbottt Laboratories, Abbottt Park, IL)

2.11. ELISA assay

The quantitative determination of inflammation-associated cytokines (TNF-alpha, IL-1beta, and IL-10) was performed using commercial colorimetric sandwich ELISA kits according to the manufacturer's instructions. In brief, samples and standards were pipetted into the wells that been have pre-coated with specific antibodies for TNF-α, IL-10 and IL1β. In next step, the wells were washed and enzyme-linked antibodies specific for TNF-α, IL-10 and IL1β were added to wells and incubated. Then, the wells were aspirated and washed. The process was repeated three times. After the last washing, aspiration was performed to remove any remaining wash buffer. The plate was inverted against clean paper towels and any unbound antibody-enzyme reagent was removed. Finally, a substrate solution containing equal volumes of Reagents A and B was added to the wells and the solution was read at 450 nm using microplate reader.

2.12. Histological assessment

At the end of experiments, the animals were decapitated under deep anesthesia and the kidney tissue samples were fixed in 10% formalin overnight and embedded in paraffin. Then, serial sections of 5 μm thickness were prepared by microtome [29,30]. Finally, H&E staining of kidney sections was done to investigate histopathological changes. A light microscope (Nikon Eclipse 80i; Tokyo, Japan) was used to investigate and photograph sections. Morphological evaluations were performed by an experienced renal pathologist, who was blinded to experimental design. Jablonski scores, a grading scale of 0–4, were used for the histopathological evaluation of samples [31]. The scoring system used is as follows: Score 0: Normal, Score 1: Mitosis and necrosis of individual cells; Score 2: Necrosis of all cells in adjacent proximal convoluted tubules, with survival of surrounding tubules; Score 3: Necrosis confined to the distal third of the proximal convoluted tubule with a band of necrosis extending across the inner cortex across the inner cortex; Score 4: Necrosis affecting all three segments of the proximal convoluted tubule.

2.13. IHC assay

To evaluate the expression of pro-inflammatory and anti-inflammatory cytokines, the slices were deparaffinized and rehydrated. Then, to block 5-micrometer sections, goat serum (10%) was used. Sections were treated with primary antibody including Anti-TNF alpha antibody (ab6671, 1/200), Anti-IL1 beta antibody (ab9722, 1/200), Anti-IL10 antibody (ab9969, 1/200) at 1 mg/ ml in 1% BSA/PBS for 60 min. After twice washing with PBS, sections were incubated again with specific horseradish peroxidase-conjugated secondary antibody for 20 min A fluorescent microscopy (Olympus, Japan) was used to investigate and photograph sections. The nuclei of cells were stained by DAPI. Data was analyzed using Image J software (NIH, Bethesda, MD, USA).

2.14. Apoptosis assay

Determination of apoptosis in kidney tissues was based on enzymatic labeling of DNA strand breaks using Cell Death Detection kit in consistent with the manufacturers' instructions. Summary, 5-micrometer paraffin sections were deparaffinized. Then, twice washing in PBS (4 min) was performed to rehydrate sections. Slices were incubated with the permeabilization solution (0.1% Triton X-100 in 0.1% sodium citrate) for 10 min at 4 °C. After twice washing in PBS (5 min), the labeling reaction was carried out by 50 μL TUNEL reagents at 37 °C for 60 min against a blank containing all components except without enzyme. Then, after again washing with PBS, the slides were treated with converter reagent for 20 min at 37 °C. The nuclei of cells were stained by DAPI. The TUNEL-positive apoptotic cells were counted in ten fields per slide and 100 cells were counted per field blinded investigator to experimental design. The apoptotic cells percentage or apoptosis index (AI) was determined according to the following formula: AI = (the number of apoptotic cells/the total number of counted cells) × 100%. A fluorescence microscopy

(Olympus Corporation, Japan) was used to detect TUNEL-positive cells. Data was analyzed using Image J software (NIH, Bethesda, MD, USA).

2.15. Statistical analysis

All the variables are expressed as means ± SEM. Analysis of data was carried out by using Prism Software, version 5. Comparison of three or more groups was performed by One-way analysis of variance followed by tukey test as post hoc analysis. Differences with a chance probability of $P < 0.05$ were accepted statistically significant.

3. Results

3.1. The effect of lavender oil on serum levels of Cr and BUN

As depicted in Fig. 1A and B, serum levels of Cr and BUN were significantly elevated in rats subjected to 45 min ischemia and 24 h
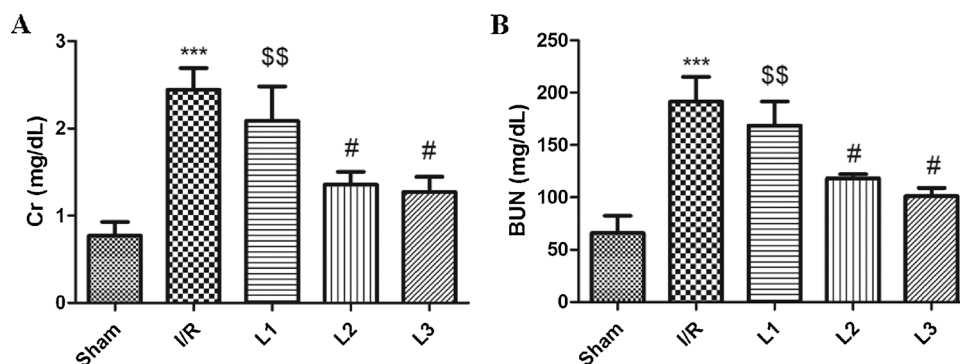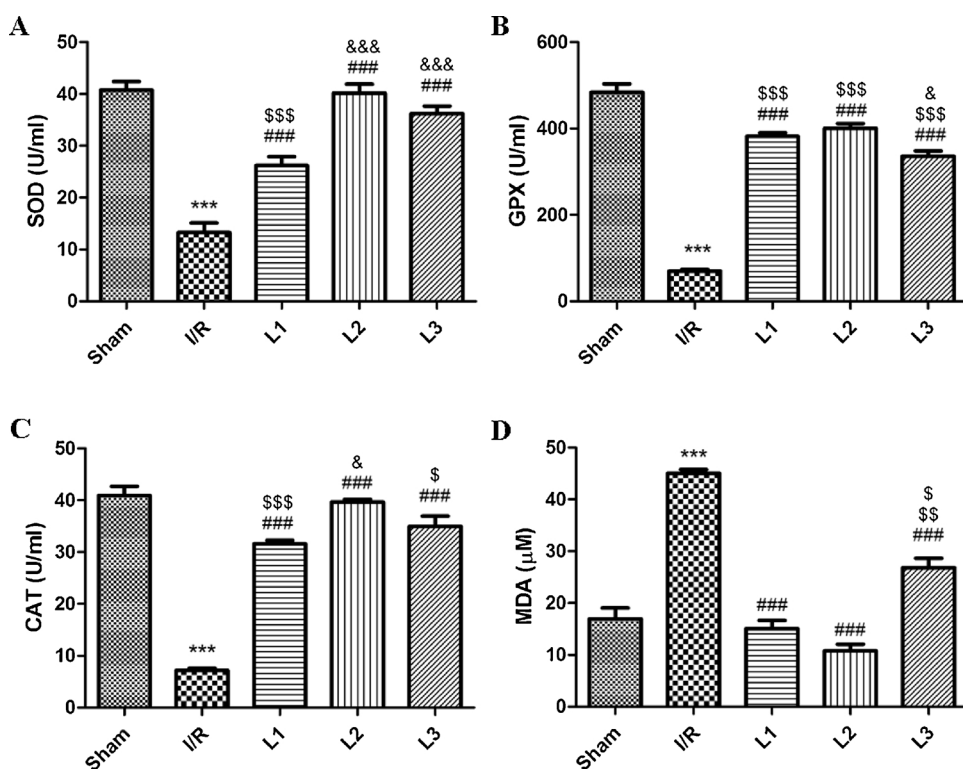

Fig. 1. Post-treatment with 100 and 200 mg/kg of lavender oil markedly improved kidney function by decreasing serum levels of Cr and BUN (*** $p < 0.001$ *vs.* sham group; # $p < 0.05$ *vs.* I/R group; $$ $p < 0.01$ *vs.* sham).

Fig. 2. Lavender oil post-treatment significantly restored activity of antioxidant enzymes and decreased lipid peroxidation. (A) SOD activity (*** $p < 0.001$ *vs.* sham group; ### $p < 0.001$ *vs.* I/R group; &&& $p < 0.001$ *vs.* L1), (B) GPX activity (*** $p < 0.001$ *vs.* sham group; ### $p < 0.001$ *vs.* I/R group; $$$ $p < 0.001$ *vs.* sham; & $p < 0.05$ *vs.* L2), (C) CAT activity (*** $p < 0.001$ *vs.* sham group; ### $p < 0.001$ *vs.* I/R group; $$$ $p < 0.001$ *vs.* sham; & $p < 0.05$ *vs.*L1), (D) MDA level (*** $p < 0.001$ *vs.* sham group; ### $p < 0.001$ *vs.* I/R group; $ $p < 0.05$ *vs.* sham and L1; $$ $p < 0.01$ *vs.*L2).

reperfusion compared with sham-operated animals. Significant decreases in Cr and BUN levels were found in rats treated with the middle (L2, 100 mg/kg) and the highest (L3, 200 mg/kg) tested concentrations of lavender oil.

3.2. The effects of lavender oil on oxidative stress markers

As shown in Fig. 2A–C, significant decreased activities of SOD, GPX and CAT were found in rats subjected to 45 min ischemia and 24 h reperfusion. Intraperitoneally administration of different doses of lavender oil at 1 h after the beginning of reperfusion markedly restored activities of SOD, GPX and CAT compared with I/R group. Our results showed that lavender oil at 100 mg/kg concentration exerted greatest protective effect against renal I/R injury. Moreover, we found that activity of SOD showed a significant decreased activity at the highest tested dose (L3, 200 mg/kg) compared with middle tested dose (L2, 100 mg/kg). Additionally, MDA level was significantly increased in I/R group relative to sham (Fig. 2D). Lavender oil post-treatment at various concentrations markedly reduced MDA levels compared with I/R group. A stronger reduced level of MDA was observed in middle tested dose (L2, 100 mg/kg) compared with the highest tested dose (L3, 200 mg/kg).

3.3. The effects of lavender oil on TNFα

Generally, IHC assay showed that the expression of TNFα was increased following I/R and reversed by different doses of lavender oil (Fig. 3A). The quantitative determination of TNFα expression was performed by ELISA assay. As depicted in Fig. 3B, the expression of TNFα was significantly increased in rats subjected to renal I/R compared with sham. Although lavender oil administration at the lowest tested dose decreased the expression of TNFα, the difference did not show a significant level. Middle and the highest tested doses of lavender oil markedly decreased the expression of TNFα compared with I/R group. There was no significant difference between middle and the highest doses of lavender oil and sham group.

3.4. The effect of lavender oil on IL1β

Similar to TNFα, IHC assay indicated that the expression of IL1β was increased in rats subjected to renal I/R and reversed by various tested concentrations of lavender oil (Fig. 4A). Additionally, the quantitative analysis by ELISA demonstrated that the expression of IL1β was markedly increased in renal I/R group compared with sham. The expression level of IL1β was slightly decreased after treatment with the lowest tested dose of lavender oil (50 mg/kg) and no significant difference was observed. Both middle and the highest tested doses of lavender oil were significantly reduced the expression level of IL1β. There was a remarkable difference between sham and the lowest tested dose of lavender oil (L1) (Fig. 4B).

3.5. The effects of lavender oil on IL10

IHC analysis demonstrated that the expression level of IL10 was decreased following I/R and reversed by different tested concentrations of lavender oil (Fig. 5A). Likewise, the quantitative determination of this anti-inflammatory cytokine by ELISA analysis showed that the expression of IL10 was significantly decreased in rats subjected to I/R compared with sham. Significant increased levels of IL10 were found after administration of middle and the highest tested doses of lavender oil (100 and 200 mg/kg) (Fig. 5B).

3.6. The effects of lavender oil apoptosis activity

In order to evaluate the effects of lavender oil on renal I/R injury, we performed TUNEL. The number of TUNEL positive cells was markedly increased in I/R group. Intraperitoneal administration of lavender oil at doses of 100 and 200 mg/kg significantly reduced apoptotic cell death. The highest tested dose of lavender oil exhibited a stronger effect for inhibition of apoptosis (Fig. 6).

3.7. The effect of lavender oil on tissue damage

As illustrated at Fig. 7, forty-five minutes renal ischemia followed by
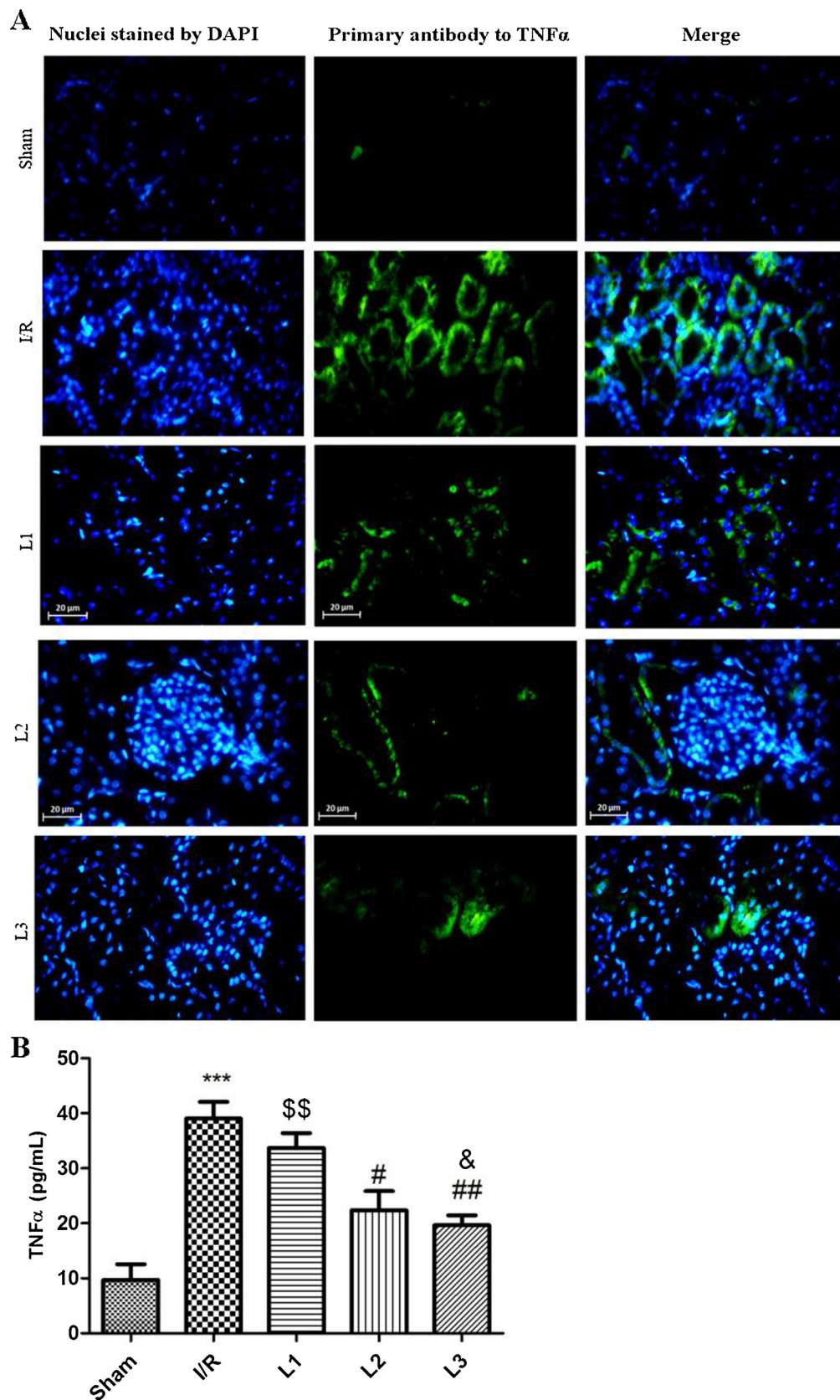
Fig. 3. Post-treatment with 100 and 200 mg/kg of lavender oil significantly decreased the expression of TNFα 24 h after reperfusion. (A) IHC assay, and (B) ELISA analysis of the TNF-α in different groups at 24 h after reperfusion (*** $p < 0.001$ and \$\$ $p < 0.01$ *vs.* sham group; #$p < 0.05$ and ##$p < 0.01$ *vs.* I/R group; & $p < 0.05$ *vs.* L1).

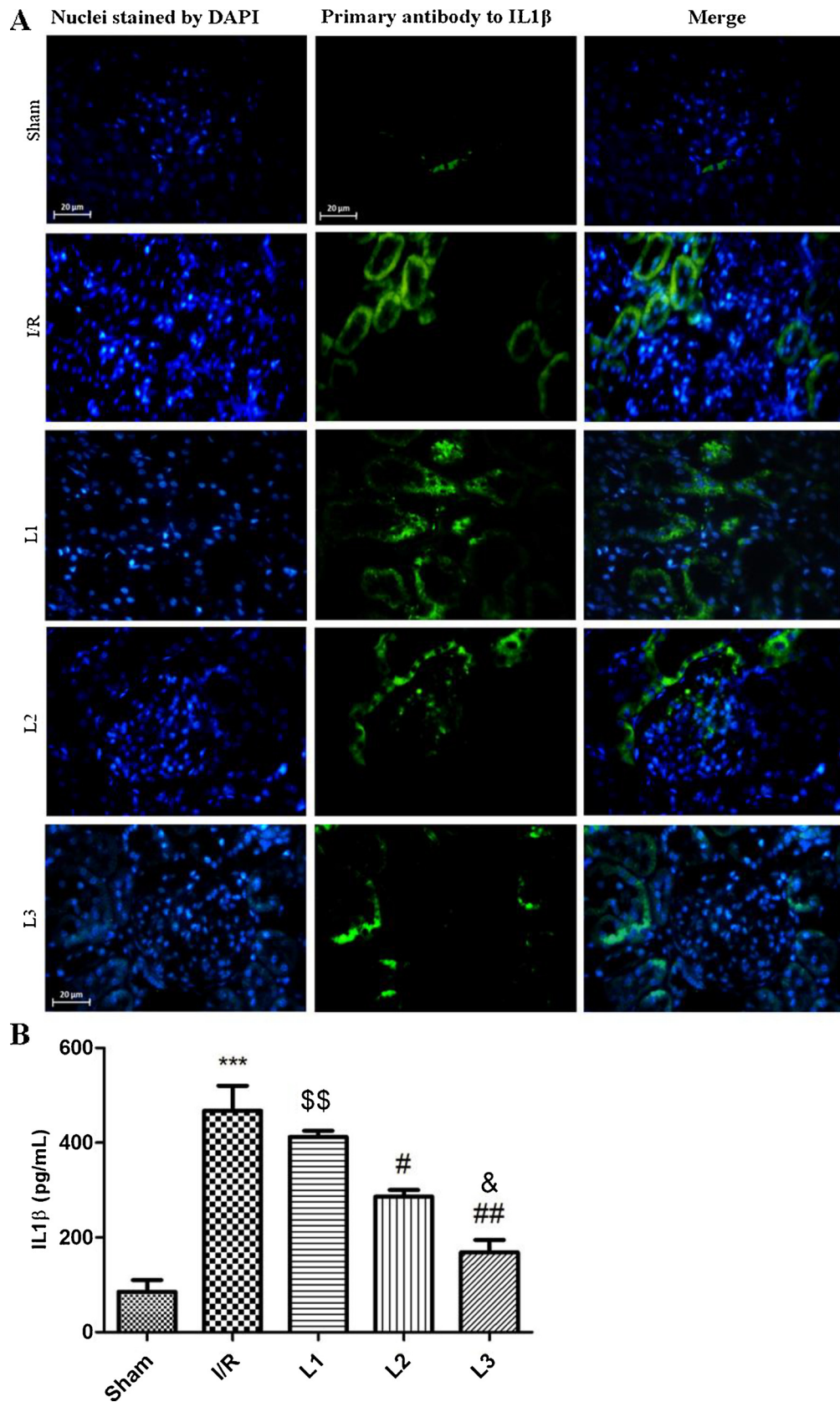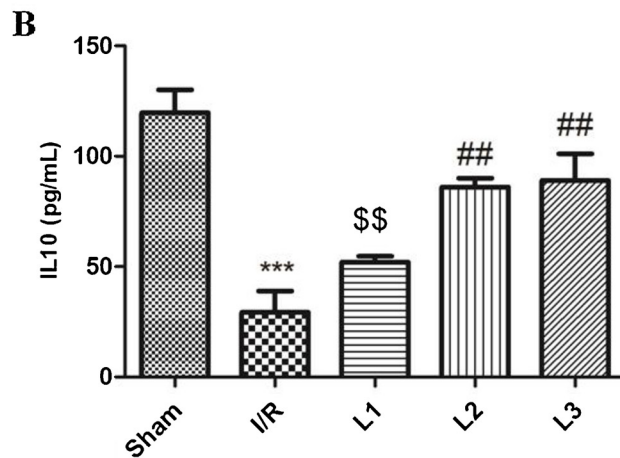**Fig. 4.** Lavender oil post-treatment decreased the expression of IL1β at 24 h after reperfusion. (A) IHC assay, and (B) ELISA analysis of the IL1β in different groups at 24 h after reperfusion (*** p < 0.001 and $$ p < 0. 01 *vs.* sham group; #p < 0. 05 and ##p < 0. 01 *vs.* I/R group; & p < 0.05 *vs.* L1).

Fig. 5. Lavender oil administration at 1 h after the beginning of reperfusion increased the expression of IL10. (A) IHC assay, and (B) ELISA analysis of the IL10 in different groups at 24 h after reperfusion (** p < 0. 01 *vs.* sham group; $$ p < 0. 01 *vs.* sham; ## p < 0. 01 *vs.* I/R group).
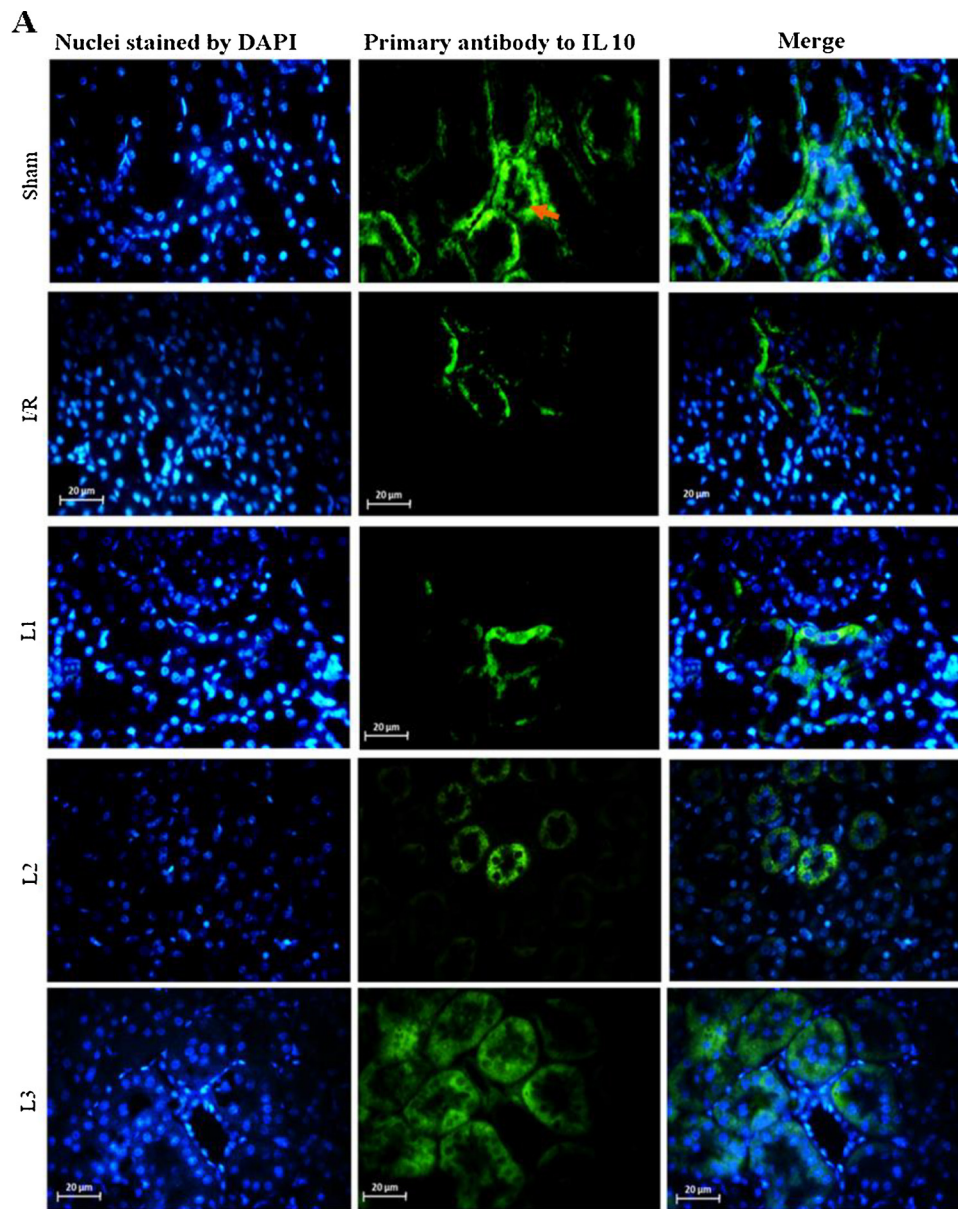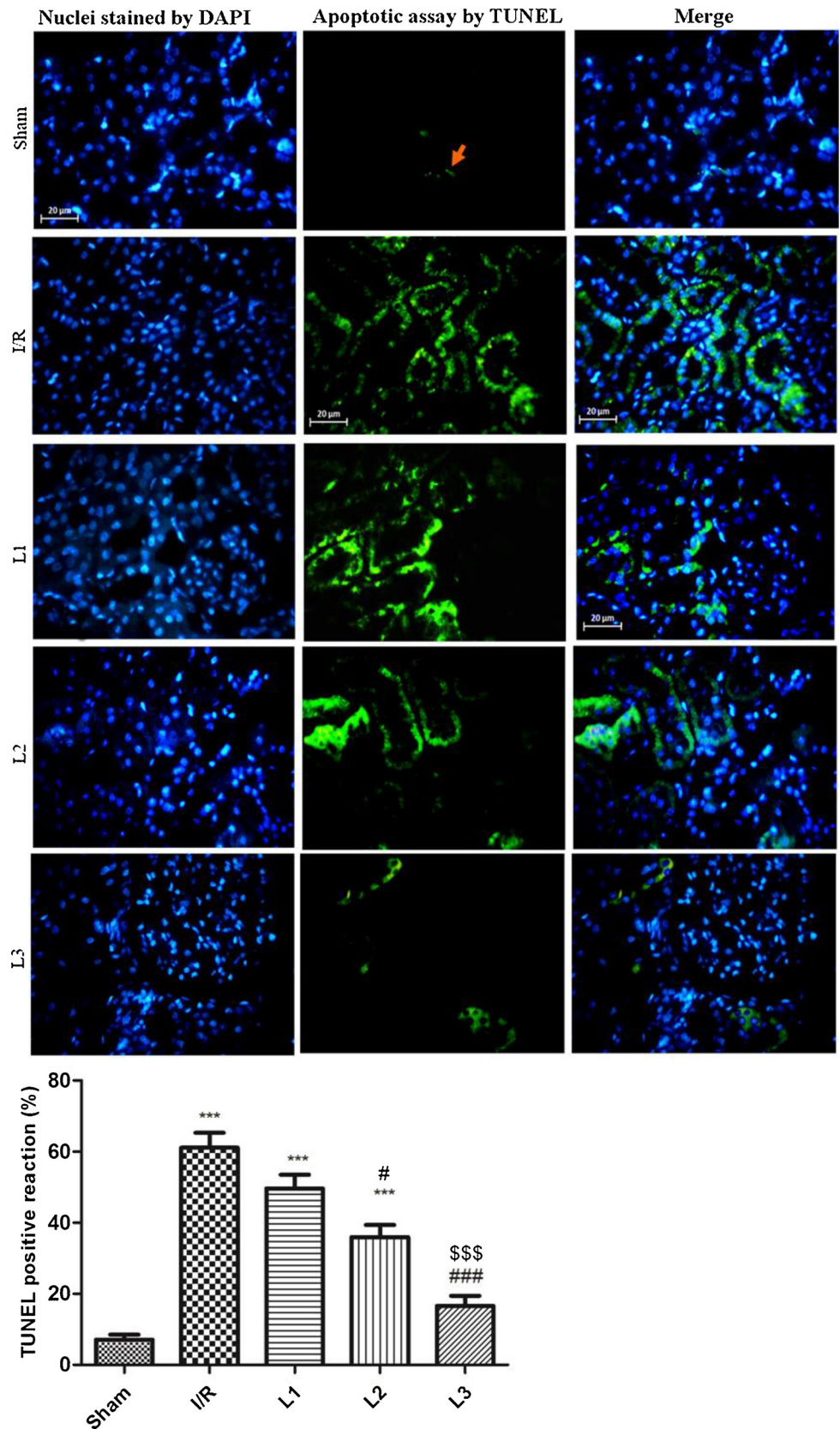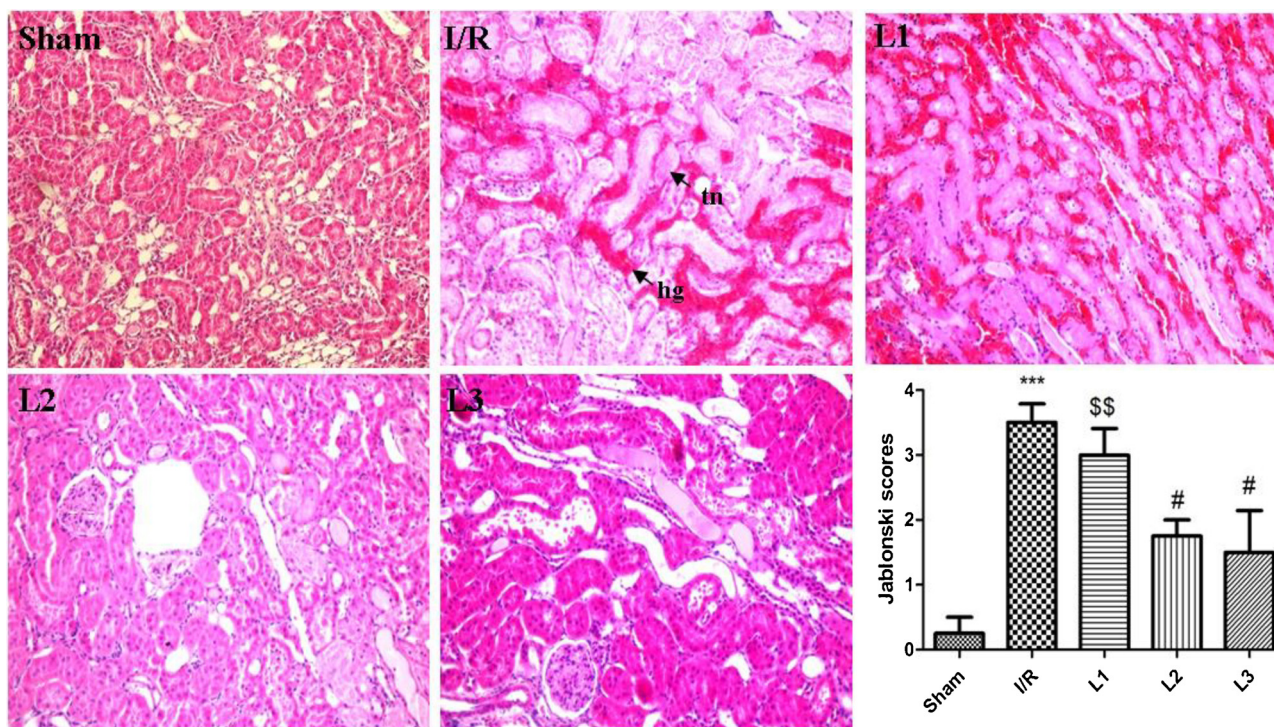
Fig. 6. Lavender oil reduced apoptotic cell death in a dose dependent mechanism (***$p < 0.001$ *vs.* sham group; #$p < 0.05$, ###$p < 0.001$ *vs.* I/R group; $$$ $p < 0.001$ *vs.*L1).

Fig. 7. Hematoxylin and eosin stained kidney sections. Ischemic changes including tubular necrosis (tn) and hemorrhage (hg) were highly observed in I/R and L1 groups at 24 h post-IR. Lavender administration at middle and the highest doses significantly decreased tissue damage. Jablonski scores demonstrated markedly increased scores in I/R compared to sham. Significant decreased scores were found in middle and the highest tested doses of lavender oil (100 and 200 mg/kg) (*** p < 0.001 and $$ p < 0.01 *vs.* sham group; #p < 0.05 *vs.* I/R group).

24 h reperfusion induced severe damage including tn and hg at 24 h post-IR in kidney tissue. A significant reduced tissue damage and preservation of morphology were seen in L2 (100 mg/kg) and L3 (200 mg/kg). According to Jablonski scores, quantitative analysis demonstrated a significantly increased score in the I/R group. Intraperitoneal administration of lavender oil at doses of 100 and 200 mg/kg markedly reduced the score.

4. Discussion

In this study, we for the first time examined the effects of lavender oil on renal injury that was induced in a rat model of renal I/R injury. Some factors such as oxidative stress markers, expression of pro and anti-inflammatory markers and apoptotic cell death have been determined. Also, renal I/R triggered a pathological cascade including enhancement of oxidative stress, initiation of acute inflammatory responses, massive tubular damage, apoptotic cell death and subsequently renal failure. Our results demonstrated that intraperitoneally lavender oil administration markedly improved kidney function and promoted cell survival through targeting oxidative stress, inflammatory cytokines, and apoptosis. A suitable option for end-stage renal disorders is kidney transplantation. Renal I/R injury is a great clinical problem after kidney transplantation which causes acute inflammatory response and subsequently decreases efficiency of this option [32–34]. Renal cells are very sensitive to alterations in oxygen tension and their endogenous antioxidant defense strongly depends on presence of high concentrations of antioxidant enzymes such as SOD, CAT, and GPx [35]. Many previous studies have shown that even delayed administration of free-radical scavenger drug reduces injury after renal I/R in animal models. This issue confirms the key role of ROS in enhancement of injury after renal I/R [36]. Excessive generation of ROS overcomes endogenous antioxidant defense which, in turn, results in ATP depletion, higher activity of membrane phospholipids proteases, elevated level of intracellular Ca^{2+} ion, alterations of mitochondrial oxidative

phosphorylation [37]. Additionally, oxygen free radicals enhance injury membrane lipid peroxidation, protein oxidation and oxidative damage of DNA [38]. Under oxidative stress, superoxide anion (O_2^-) interacts with NO and disrupts nitroso-redox imbalance. This imbalance leads to generation of reactive compounds like peroxynitrite. Oxidation of lipids can be a consequence of peroxynitrite formation [39]. In this study, our results showed that induction of renal I/R injury markedly decreased activities of antioxidant enzymes such as SOD, CAT, and GPx and enhanced lipid peroxidation. Intraperitoneal injection of various concentrations of lavender oil contributes to activity restoration of antioxidant enzymes and inhibition of lipid peroxidation. In keeping with our findings, many previous studies have indicated that smelling or inhalation of lavender oil can exert protective effects against dementia, diabetes, and myocardial infarction by increasing free radical scavenging activity and targeting oxidative stress [40–42]. After reperfusion, owing to hypoxic cellular injury, secretion of some factors and structural alterations in cell surfaces or proteins evokes the immune system. In fact, during reperfusion, necrotic or injured renal cells initiate release of some factors such as high mobility group 1 protein that is a strong stimulator of leukocyte infiltration and TNF-α production. On the other hand, production of IL1β can evoke the TECs to produce TNF-α and IL-6 that, in turn, result in extension of injury [43]. A study by Jevnikar et al. reported that IL-18 acts as a stimulator of TECs for the secretion of pro-inflammatory cytokines including IL-1β, TNFa, and IL-6 which are hallmarks of renal I/R and exacerbate injury [44]. In consistent with previous studies, our findings showed that expression levels of pro-inflammatory cytokines were markedly elevated in rats subjected to renal I/R injury and reversed by various concentrations of lavender oil. In the case of inflammatory cytokines, the protection was in dose dependent manner. On the other hand, previous studies have shown overexpression of IL-10 after reperfusion can reduce neutrophil recruitment and secretion of pro-inflammatory cytokines [45]. A recent study by Soranno et al. showed that using injectable hydrogels as carriers for delivery of IL-10 to the ischemic kidney improved renal

outcomes by targeting systemic inflammation [46]. According to these previous findings, our study demonstrated that post-treatment with lavender oil increased the expression of IL-10 in a dose-dependent mechanism. In consistent with our findings, some previous studies have indicated that lavender reduced LPS-Stimulated Inflammation by targeting pro-inflammatory cytokines and membrane Toll-like receptors [47]. To obtain greater insights of protective effects of lavender oil against renal I/R injury, we also investigated apoptosis activity using TUNEL staining in different groups. The kidneys of the I/R group had more TUNEL positive cells relative to sham. Our findings showed that intraperitoneal administration of lavender oil reduced apoptotic cell death in a dose-dependent manner. In agreement with our results, Vakili et al. reported that lavender oil exerted neuroprotective effects on an animal model of ischemic stroke through inhibition of apoptosis [27]. Our results demonstrated that lavender oil reduced damage to peritubular capillaries, tubular necrosis, and preserved normal morphology of nephrons.

5. Conclusion

Collectively, our findings demonstrate that lavender oil can act as a potent anti-inflammatory agent against renal I/R injury. Moreover, it can reduce injury through targeting oxidative stress and apoptosis. Lavender oil can be presented as a good candidate for future drug design to accelerate recovery of kidney function after kidney transplantation.

Author contribution statement

Nahid Aboutaleb conceived and designed research. Hosein Jamali conducted experiments. Hamidreza Pazoki-Toroudi contributed new reagents or analytical tools. Maryam Abolhasani and Nahid Aboutaleb analyzed data. Nahid Aboutaleb wrote the manuscript. All authors read and approved the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgement

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