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ORIGINAL ARTICLE / ÖZGÜN MAKALE

TAURINE PREVENTS AGAINST 2,3,7,8-TETRACHLORODIBENZO-P-DIOXIN-INDUCED OXIDATIVE STRESS IN THE LIVER AND KIDNEY OF RATS

TAURİN, SIÇAN KARACIĞER VE BÖBREK DOKULARINDA 2,3,7,8-TETRAKLORODİBENZO-P-DİOKSİN KAYNAKLI OKSİDATİF STRESİ ÖNLER

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ABSTRACT

Objective: *The aim of the study was to investigate the preventive effects of taurine against 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)-induced organ damage in rats. The environmental toxin TCDD has a high toxicity in animal and human tissues. Taurine is an amino acid found in many organs, with multiple physiological roles including the protection of cells with its antioxidant and anti-inflammatory properties. In this context, our aim in this study was to investigate the potential preventive effect of taurine on oxidative stress and organ damage caused by TCDD in rat liver and kidney tissues. To evaluate these possible effects, we measured the levels of thiobarbituric acid reactive substances (TBARS), and glutathione (GSH), as well as the activity of superoxide dismutase*

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(SOD). In addition, immunohistochemical detection of caspase-3 expression, and the assessment of histopathological changes in tissue samples were performed.
Material and Method: *Adult male Wistar rats (250-300 g, 12-13 weeks, n = 32) were randomly allocated into four groups (n = 8/group): Control, TCDD, TAU, and TCDD+TAU. TCDD and/or taurine were administered via gavage in doses of 2 µg/kg/week and 200 mg/kg/day, respectively.*
Result and Discussion: *The results showed that TCDD caused oxidative stress in the liver and kidney tissues of rats by decreasing the levels of GSH and SOD activity and increasing the levels of TBARS. Taurine treatment significantly reduced TBARS levels ($p<0.05$), it significantly increased GSH levels and SOD activity ($p<0.05$) in the concurrent administration of TCDD and taurine. Taurine also reduced the histopathological changes caused by TCDD-induced oxidative stress in the liver and kidney tissues. Taurine prevented the apoptotic pathway by decreasing cysteine aspartate specific protease-3 (caspase-3). Taurine supplementation helps to regulate oxidative imbalance and reduces histopathological changes caused by TCDD-induced organ damage. This could be a novel approach to avoiding TCDD toxicity.*
Keywords: *Oxidative stress, rats, taurine, TCDD*

ÖZ

Amaç: *Çalışmanın amacı, sıçanlarda 2,3,7,8-tetrachlorodibenzo-p-dioksin (TCDD) kaynaklı organ hasarına karşı taurinin önleyici etkilerinin araştırılmasıdır. Çevresel toksin TCDD, hayvan ve insan dokularında yüksek toksisiteye sahiptir. Taurin, birçok organda bulunan bir amino asit olup, antioksidan ve antienflamatuar özellikleri ile hücrelerin korunmasında görev alır. Bu kapsamda, bu çalışmadaki amacımız, TCDD'nin sıçan karaciğer ve böbrek dokularında neden olduğu oksidatif stres ve organ hasarları üzerinde taurinin potansiyel önleyici etkisini araştırmaktır. Bu olası etkileri değerlendirmek üzere, tiyobarbitürik asitle reaksiyona giren reaktif maddeler (TBARS) ve glutatyon (GSH) düzeylerinin yanı sıra süperoksit dismutazın (SOD) aktivitesi ölçülmüştür. Ayrıca, kaspaz-3 ekspresyonunun immünohistokimyasal tespiti ve doku örneklerinde histopatolojik değişikliklerin değerlendirilmesi gerçekleştirilmiştir.*
Gereç ve Yöntem: *Yetişkin erkek Wistar sıçanları (250-300 g, 12-13 hafta, n = 32) rastgele dört gruba (n = 8/grup) ayrıldı: Kontrol, TCDD, TAU ve TCDD+TAU. TCDD ve/veya taurin gavaj yoluyla sırasıyla 2 µg/kg/hafta ve 200 mg/kg/gün dozlarında uygulandı.*
Sonuç ve Tartışma: *Bulgular, TCDD'nin GSH düzeyi ve SOD aktivitesini azaltarak ve TBARS düzeylerini artırarak sıçanların karaciğer ve böbrek dokularında oksidatif strese neden olduğunu göstermiştir. Taurin uygulaması, TCDD ve taurinin eşzamanlı uygulamasında TBARS düzeylerinde önemli ölçüde azalma ($p<0.05$), GSH düzeylerinde ve SOD aktivitesinde ise önemli ölçüde artış sağlamıştır ($p<0.05$). TCDD'nin karaciğer ve böbrek dokularında neden olduğu oksidatif kaynaklı histopatolojik değişiklikler de taurin uygulaması ile azalmıştır. Taurin, sistein aspartat spesifik proteaz-3'ü (kaspaz-3) azaltarak apoptotik yolağı engelledi. Taurin takviyesi, oksidatif dengesizliği düzenlemeye yardımcı olmakta ve TCDD'nin neden olduğu organ hasarının göstergesi olan histopatolojik değişiklikleri azaltmaktadır. Bu, TCDD toksisitesinden kaçınmak için yeni bir yaklaşım olabilir.*
Anahtar Kelimeler: *Oksidatif stres, sıçanlar, taurin, TCDD*

INTRODUCTION

The environmental contaminant 2,3,7,8-tetrachlordibenzo-*p*-dioxin (TCDD) is a high-toxic persistent organic pollutant that bioaccumulates and biomagnifies in animal fat and plant tissues [1]. Because TCDD is a fat-soluble chemical, it is easily bioconcentrated in animal fat stores and then in human tissue [2]. It has received a lot of attention in the recent literature especially with regard to its toxic effects such as hepatotoxicity [3], nephrotoxicity [4], immunotoxicity [5], and reproductive damage [6]. The aryl hydrocarbon receptor (AHR), a ligand-dependent transcription factor with a high affinity for TCDD, is known to mediate TCDD toxicity [7]. The activation of the AHR by TCDD affects the cellular redox homeostasis to induce an oxidative stress response, which is a crucial mechanistic component of many toxicologic processes [8]. TCDD-mediated oxidative damage has been observed in such as the liver [9], testis [10], and kidneys [11] in experimental animal studies. Taurine is a sulfur-containing intracellular amino acid that is involved in neuromodulation, thermoregulation, osmoregulation, calcium regulation, antioxidant defense, apoptosis, and vascular activities in tissues

like the brain, heart, muscle, and blood [12]. Taurine's antioxidant activity is one of its most essential properties, and taurine supplementation strengthens the antioxidant defense system by preventing the loss of antioxidant enzymes due to oxidative stress [13]. Thiobarbituric acid reactive substances (TBARS), which has cytotoxic characteristics, superoxide dismutase (SOD), and glutathione (GSH) are all key indicators of oxidative organ damage [14,15]. Taurine's effect on SOD activity, GSH content, and malondialdehyde (MDA) in mice liver and kidney have been shown to decrease oxidative stress after ethanol exposure [16]. It has been demonstrated that taurine enhances antioxidant defense mechanisms in the testis and epididymis of hypertensive rats [17]. The purpose of this study was to investigate the effect of taurine on TCDD-induced oxidative organ damage by evaluating at histopathological changes and oxidative parameters including TBARS, SOD activity, and GSH in the liver and kidney of rats.

MATERIAL AND METHOD

Experimental Protocol

Taurine was purchased from Carl Roth (Karlsruhe, Germany). TCDD was obtained from AccuStandard (>99% purity).

In this study, adult male Wistar rats (250-300 g) aged 12-13 weeks were used. All animals were fed rodent pellets and water on an ad-libitum and were housed in cages at room temperature (25 ºC) and humidity (50-55%) with a light-day cycle. Experimental procedures were conducted in accordance with the Guide for Care and Use of Laboratory Animals under the approval of the Pamukkale University Animal Experiments Local Ethics Committee (Protocol no. PAUHDEK-2021/50). A total of 32 rats were randomly divided into four groups of eight each (n=8). All treatments were administered via oral gavage. 1: Control; only corn oil was administered. 2: TCDD; Once a week, rats were given TCDD suspended in corn oil at a dose of 2 ug/kg. 3: TAU; Taurine was administered at a dose of 200 mg/kg. 4: TCDD + TAU: Rats were given a combination of TCDD and Taurine (TCDD+TAU). The dose of TCDD was chosen based on previous studies [18,19]. Animals were sacrificed under anesthesia 30 days following treatment (xylazine, 8-10 mg/kg and ketamine hydrochloride 80-100 mg/kg intraperitoneally). For biochemical analysis, liver and kidney tissues were quickly dissected and stored at −80°C until analysis. Samples from these tissues were fixed in 10% formaldehyde solution for histopathological evaluation.

Biochemicals Assay

Tissue samples were homogenized with PCV Kinematica Status Homogenizer using phosphate buffered saline at pH 7.4. The resulting homogenates were sonicated for three cycles (40 s on ice after 20 s sonication) using the Bronson sonifier 450. Tissues were centrifuged at 1500 g for 10 minutes at 4°C, and supernatants were stored at -20°C for later analysis. The TBARS level was determined using Yagi's method [20]. The color produced by the reaction of MDA and thiobarbituric acid (TBA) is spectrophotometrically measured in this method. The resulting absorbance was measured spectrophotometrically at a wavelength of 532 nm. The TBARS level was given in nmol/g tissue. SOD activity was determined using the method developed by Sun et al. [21]. The TBARS level was given in nmol/g tissue. The inhibition of nitroblue tetrazolium reduction by xanthine-xanthine oxidase as a superoxide generator is associated with superoxide dismutase activity. After that, the formazan product was spectrophotometrically measured at 560 nm. The results are given in units of U/mg protein. Reduced GSH levels of tissue homogenates were measured at 412 nm spectrophotometrically [22]. The GSH level was given in nmol/ml protein. The protein content of tissue homogenates was determined using the Lowry method and bovine serum albumin as the standard [23].

Histopathological Examination

Tissue samples from the kidney and liver were fixed in 10% formalin for histopathological examination. Following routine tissue processing, the samples were embedded in paraffin. Sections of 5 mm thickness were taken from each block, affixed to slides and stained with Hematoxylen-Eosin (H&E). The sections were examined using a light microscope (Leica DFC 280). Histopathological

assessment of damage was calculated based on the severity of the damage to 0 (none), 1 (mild), 2 (moderate), 3 (severe).

Immunohistochemical Examination

Sections taken from kidney and liver tissues for immunohistochemical analysis were adhered to slides coated with poly-lysine. After rehydration, tissue samples were microwaved for 20 minutes in citrate buffer (pH 7.6). The sections were washed again with phosphate buffer after being left at room temperature for 20 minutes during the cooling stage. The sections were immersed in a 0.3% H_2O_2 solution for 7 minutes before being washed with phosphate buffer. The Caspase-3 kit protocol was applied to the prepared sections in accordance with the manufacturer's instructions. Accordingly, the primary rabbit-polyclonal was incubated with Caspase-3 antibody (Ab4051, Abcam) for 2 h. The biotinylated goat was rinsed in phosphate buffer and treated with an anti-polyvalent for 10 min. After that, it was incubated for 10 minutes at room temperature with streptavidin peroxidase. Following the completion of the chromogen substrate staining, the slides were treated for 1 min with Mayer hematoxylin and dehydrated by rinsing in tap water. Caspase-3 positive cell numbers were counted in 10 randomly selected fields from each section and score tables were prepared for immune positive cells between groups.

Statistical Analysis

SPSS 25.0 package program (Chicago, IL, USA) was used for statistical analysis. All values were presented as mean ± standard error of means (SEM). Statistical significance was accepted as $p<0.05$. ANOVA and post hoc Tukey tests were performed to compare data between experimental groups in biochemical parameters ($p<0.05$). Histological parameters were calculated using the SPSS computer program (SPSS 20, SPSS Inc., Chicago IL, USA) and the MedCalc 11.0 (Belgium) statistical programs. The results were presented as mean ± (SEM). Kruskal-Wallis and Connover tests were used for comparisons between groups.

RESULT AND DISCUSSION

Biochemical Results

As shown in Figure 1A, 1B, 1C GSH and SOD levels in liver tissue of rats administered TCDD were significantly decreased compared to the CONTROL group ($p<0.001$). The GSH level and SOD activity in the liver tissues of the TCDD+TAU group were significantly increased compared to the TCDD group ($p<0.001$). TBARS levels were associated with a significant increase in the liver tissues of TCDD-treated rats compared to CONTROL groups ($p<0.001$). Conversely, it was determined that TBARS levels in liver tissues decreased in the taurine-administered TCDD group ($p<0.05$). In addition, there was no statistically significant difference between TAU and CONTROL groups in terms of TBARS, SOD and GSH levels.

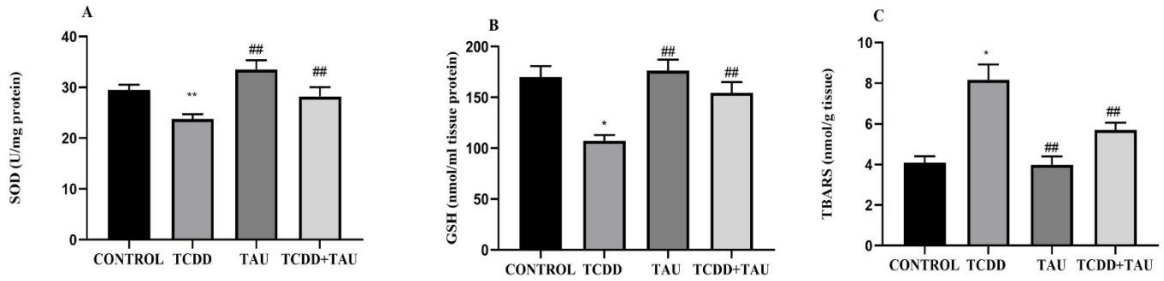

Figure 1. Liver tissue markers of oxidative stress (n=8, for each group). (A) SOD activity in liver tissue. (B) GSH content of liver, (C) TBARS level in liver. Significantly different from Control groups *(*; $p<0.05$,**; $p<0.001$)*. Significantly different from TCDD groups (#; $p<0.05$, ##; $p<0.001$).

As illustrated Figure 2, SOD activity and GSH level in kidney tissue were decreased in the TCDD group compared with the CONTROL group ($p<0.001$). When compared with the TCDD group, the SOD activity and GSH content increased significantly in the TCDD+TAU group ($p<0.001$). Results indicated a significant increase of TBARS level in TCDD administrated group compared with CONTROL group ($p<0.001$). Combined administration of TCDD and taurine was effective in reversing TBARS levels to similar values than those of CONTROL group. The levels of SOD, GSH, and TBARS in the TAU group were not statistically different from those in the CONTROL group ($p>0.05$).

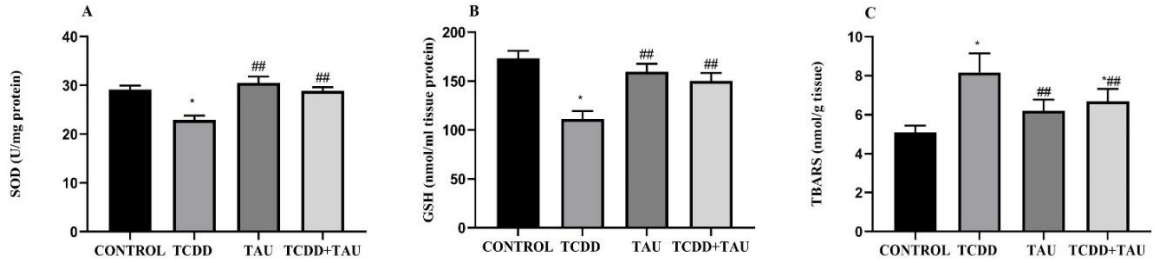

Figure 2. Kidney tissue markers of oxidative stress (n=8, for each group). (A) SOD activity in kidney tissue. (B) GSH content of kidney, (C) TBARS level in kidney. Significantly different from Control groups *(*; $p<0.05$,**; $p<0.001$)*. Significantly different from TCDD groups (#; $p<0.05$, ##; $p<0.001$).

Histological Evaluations

Histologically, the CONTROL (Figure 3A) and TAU (Figure 3B) groups appeared normal. In the TCDD group, liver tissue showed vascular congestion (black asteriks) (Figure 4A,4B), mononuclear cell infiltration (black arrows) (Figure 4A,4B,4D), apoptotic cell in vena centralis (blue arrow) (Figure 4C), eosinophilic stained and pyknotic nuclei cells (Figure 4B,4D,4E), sinusoidal dilatation (Figure 4C,4E). In TCDD + TAU group, liver damages were decreased compared with TCDD group. Little hemorrhage (Figure 5A), mononuclear cell infiltration (thick black arrow) (Figure 5B), and vascular congestion (black asteriks) (Figure 5B) were observed in TCDD + TAU group. Normal histological appearance in kidney tissue were detected in the CONTROL (Figure 6A) and TAU (Figure 6B) group.

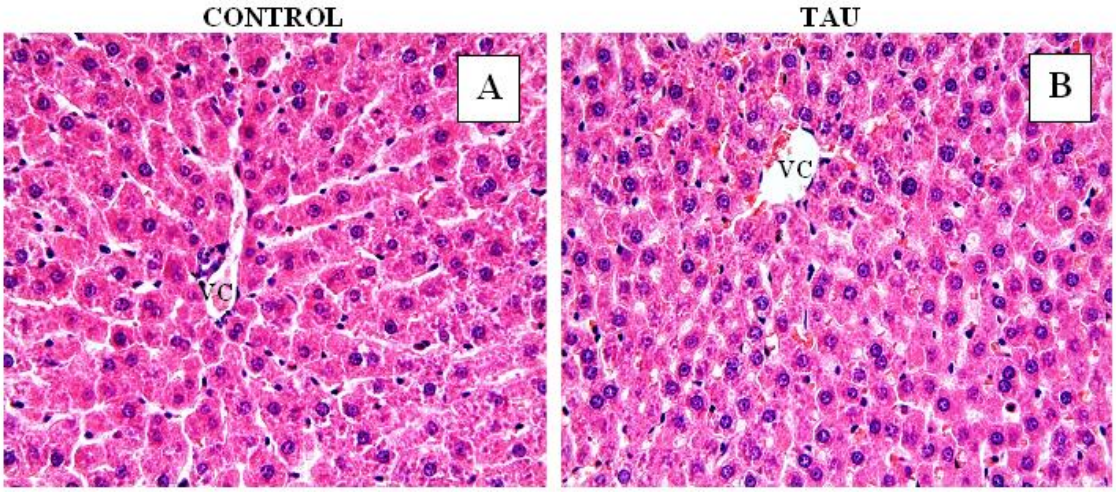

Figure 3. The liver tissue in the CONTROL (A) and TAU (B) groups appeared histologically normal. A, B: X40 (H&E).

The glomerular complex, renal tubules, and tubular epithelial cell membrane contour were all regular in the CONTROL and TAU groups. In TCDD group, glomerular degeneration (Figure 7A,7B) (white arrows), dilatation of the tubular lumen (Figure 7B,7C,7D), inflammatory cell infiltration (thick black arrows) (Figure 7A,7C), narrowing in the bowman area (Figure 7B,7C), epithelial atrophy and cell desquamation (Figure 7C,7D), casts in tubular lumen (Figure 7C) (black asteriks), hemorrhage between the tubules (Figure 7E) were observed. Kidney damage was reduced in the TCDD + TAU group compared to the TCDD group. Little hemorrhage between the tubules (Figure 8A), and cell desquamation (Figure 8B) were observed in TCDD + TAU group. In addition, histopathological damage score results in liver and kidney tissues of all groups are presented in Table 1. Histological alterations in all organs were more severe in the TCDD treatment group than in the TCDD and TAU administration group combined.

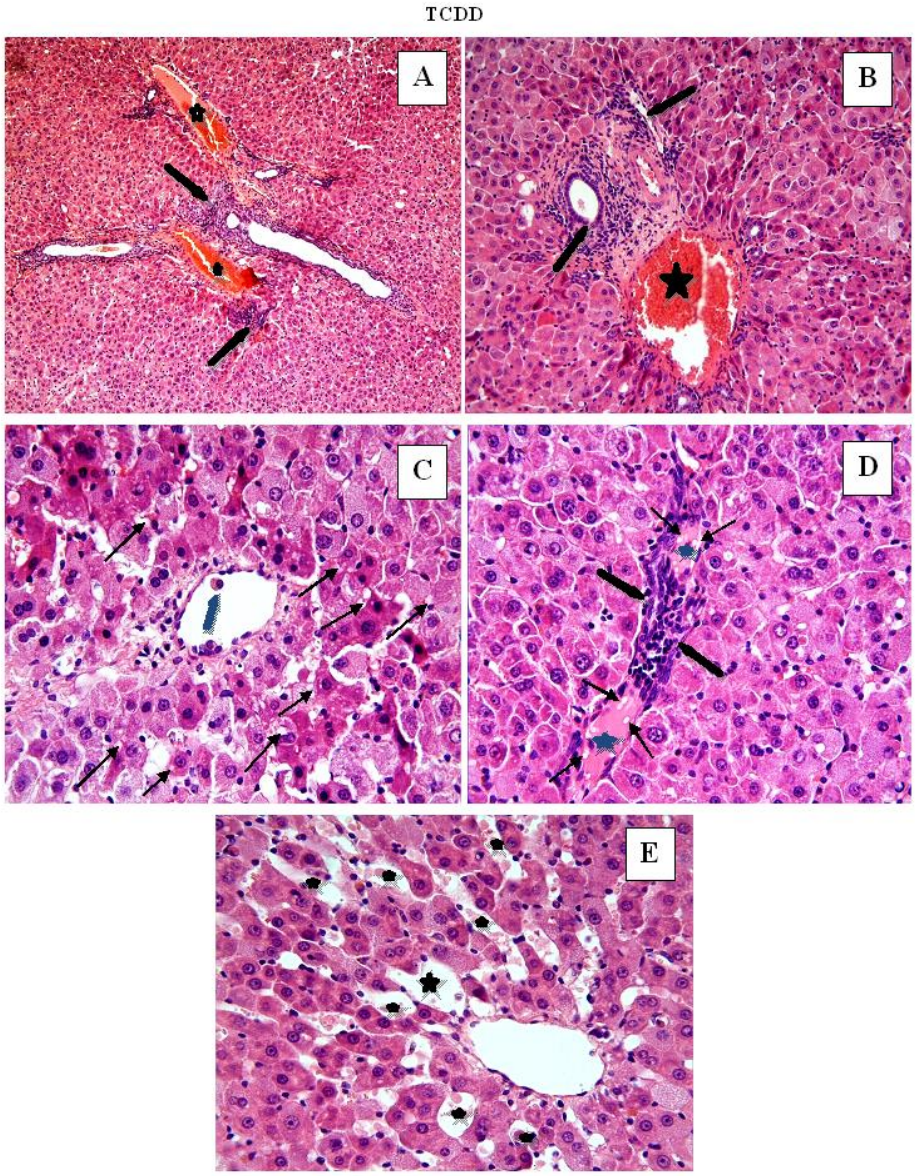

Figure 4. In TCDD group, vascular congestion (black asteriks) (A,B), mononuclear cell infiltration (black arrows) (A,B,D), apoptotic cell in vena centralis (blue arrow) (C), eosinophilic stained and pyknotic nuclei cells (B,D,E), sinusoidal dilatation (C,E), oedema (black asteriks) and vacuolisation (C,E) were observed in liver tissue. A: X10; B: X20; C, D, E: X40 (H&E).

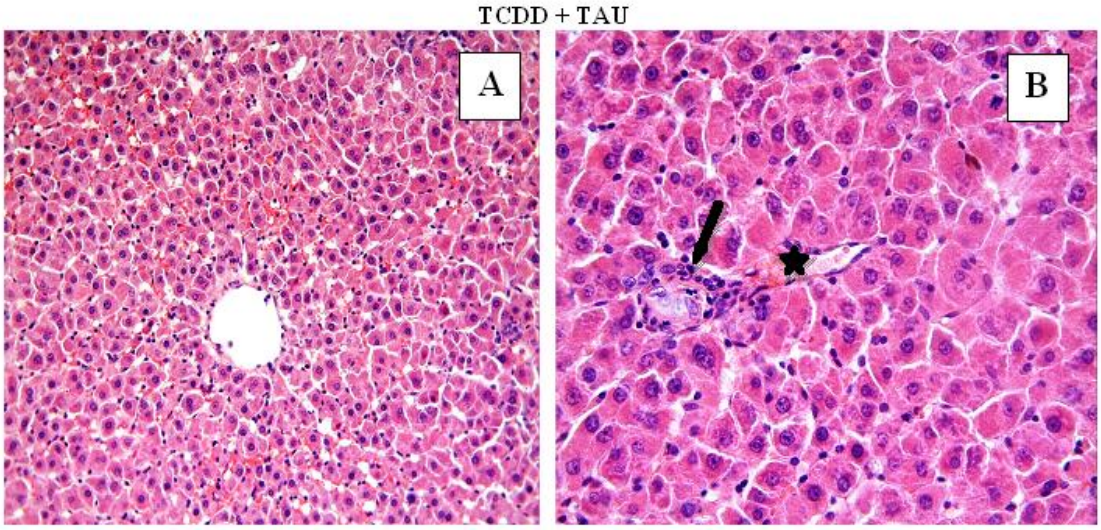

Figure 5. In comparison to the TCDD group, liver damage was decreased in the TCDD + TAU group. Little hemorrhage (A), mononuclear cell infiltration (thick black arrow) (B), vascular congestion (black asteriks), and (B) were observed in TCDD + TAU group. A: X20, B: X40 (H&E).

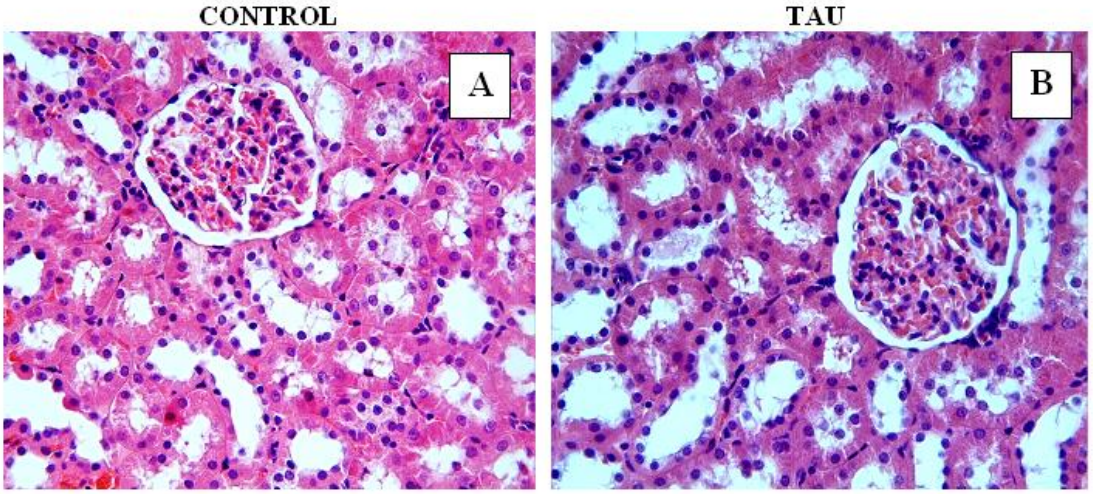

Figure 6. Normal histological appearance was detected in the CONTROL (A) and TAU (B) groups in the kidney tissue. CONTROL and TAU groups revealed regular morphology of glomerular complex, renal tubules with intact tubular epithelial cell membrane contour in CONTROL and TAU group. A, B: X40 (H&E).

Table 1. Histopathological score of groups. (Mean ± SEM)

Groups	Histopathologic Damage (Mean±SE)	
	Liver	Kidney
CONTROL	$0.47 \pm 0.09^{*}$	$0.57 \pm 0.09^{*}$
TCDD	$1.86 \pm 0.12^{\#}$	$2.04 \pm 0.87^{\#}$
TAU	$0.91 \pm 0.10^{*}$	$0.89 \pm 0.09^{*}$
TCDD+TAU	$1.17 \pm 0.11^{+}$	$1.57 \pm 0.11^{+}$

The mean differences between values with different superscripts in the same column were statistically significant (n=8) ($p \leq 0.001$). The mean differences between values with the same superscript in the same column were not statistically significant (n=8) ($p > 0.05$). *, #, and + superscripts express statistical significance of histopathological damage between groups in liver and kidney tissue. Each value is the mean ± standard error of the mean.

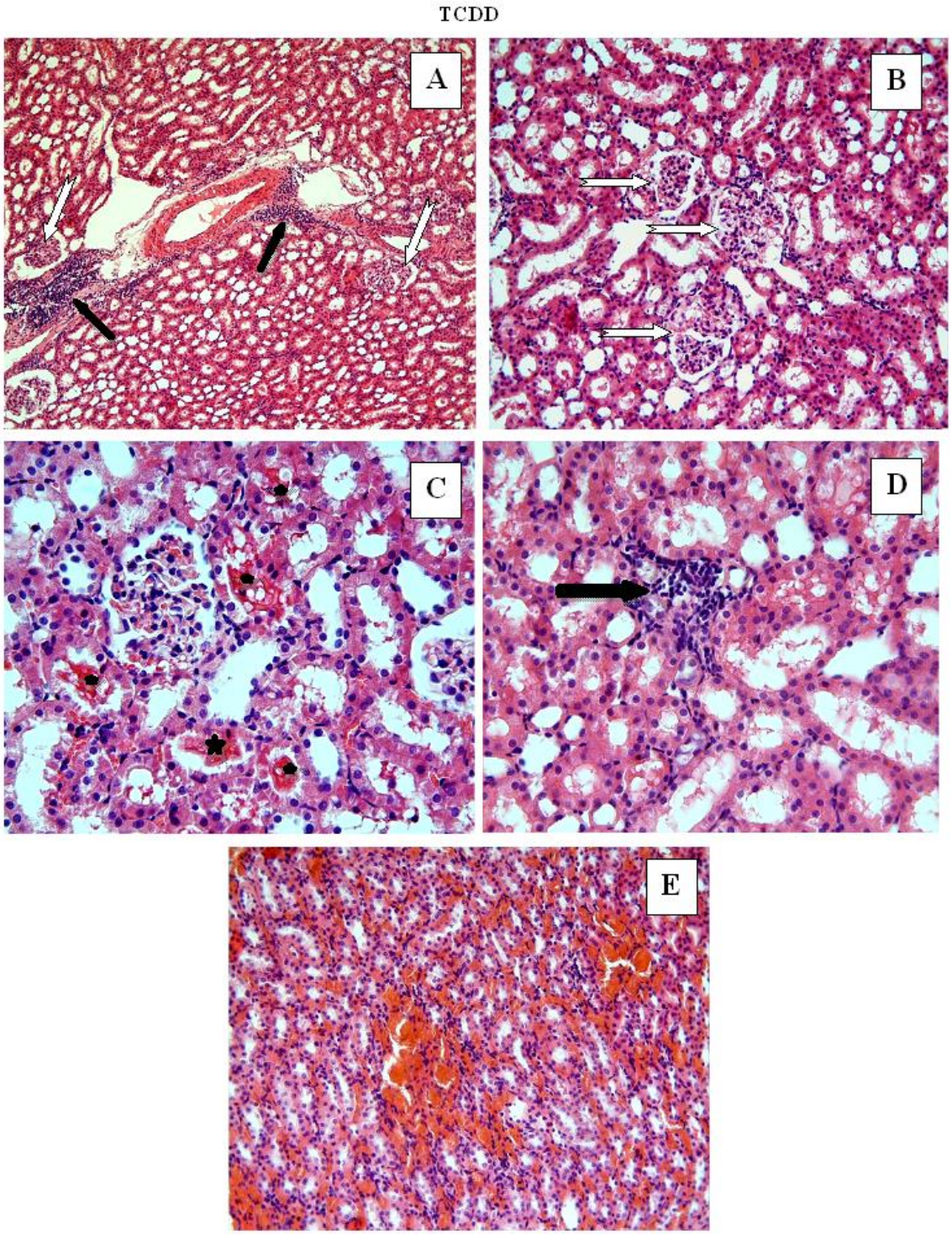

Figure 7. In TCDD group, glomerular degeneration (A,B) (white arrows), dilatation of the tubular lumen (B,C,D), inflammatory cell infiltration (thick black arrows) (A,C), narrowing in the bowman area (B,C), epithelial atrophy and cell desquamation (C,D), casts in tubular lumen (C) (black asteriks), hemorrhage between the tubules (E), were observed. A: X10; B,E: X20; C,D: X40 (H&E).

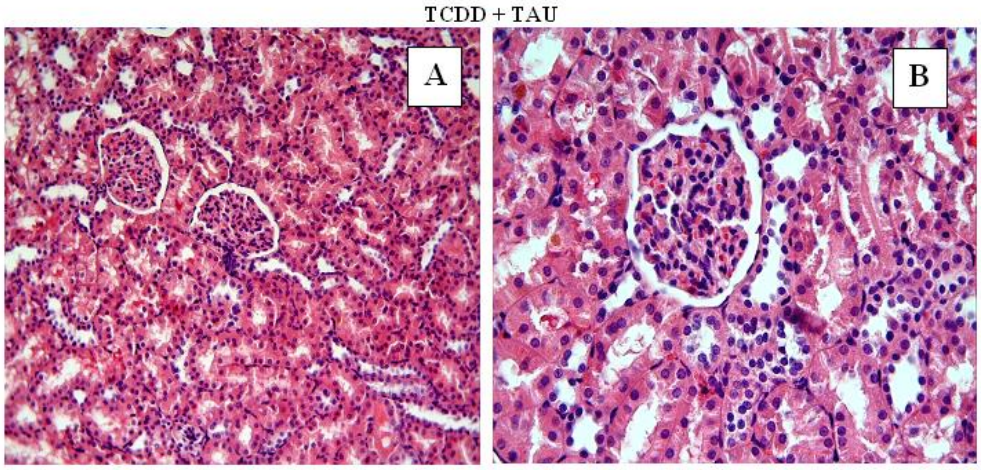

Figure 8. In TCDD + TAU group, kidney damages were decreased compared with TCDD group. Little hemorrhage between the tubules (A), and cell desquamation (B) were observed in TCDD + TAU group. A: X20; B: X40 (H&E).

Immunohistochemical Evaluations

We evaluated liver and kidney tissues for Caspase-3 activity. There were no positive stained cells in CONTROL (Figure 9A, 10A) and TAU (Figure 9D, 10D) groups. In TCDD (Figure 9B, 10B) and TCDD+ TAU (Figure 9C, 10C) groups, Caspase-3 positive stained cells were observed in both organs. In TCDD + TAU group, positive stained cells were decreased compared with TCDD group in liver and kidney tissues. The intensity of caspase-3 positive staining score in liver and kidney tissue is given in Tables 2 and 3, respectively.

In this study, taurine was assessed for its preventive effect in TCDD-induced hepatotoxicity and nephrotoxicity in male Wistar rats by analyzing histopathological and oxidative stress markers such as TBARS, SOD activity, and GSH tissue contents. Subchronic and chronic TCDD exposure causes an increase in the production of ROS, lipid peroxidation, and DNA damage in rats [24,25]. The AHR signal transduction pathway is known to be responsible for the majority of TCDD's *in vivo* toxic effects [26]. Histopathological examination and oxidative marker levels in our study showed that TCDD causes severe damage to tissues. TCDD significantly increased oxidative damage by increasing TBARS levels, decreasing GSH levels and SOD enzyme activity in the liver and kidney tissues.

Taurine is an important homeostasis mediator with multiple roles in protecting against oxidative stress [27]. Our findings show that taurine at a dose of 200 mg/kg/day alleviated the oxidative stress and organ damage induced by TCDD in rats. In a previous study, we have demonstrated that capsaicin has a curative effect by reducing oxidative stress in TCDD-induced organ damage in rats' kidney and liver [28]. SOD activity and GSH levels are critical in the detoxification of superoxide radicals, which protect cells from free radical damage [29]. TBARS are formed as a result of ROS peroxidizing fatty acids, and they cause irreversible cell damage [30]. In rat liver damage caused by TCDD, the antioxidants quercetin [31] and hesperidin [32] have been shown to reduce MDA levels while increasing GSH and SOD levels. Taurine has been shown to scavenge ROS and reduce lipid peroxidation, which helps to stabilize biological membranes [33]. TCDD significantly altered the levels of oxidative stress markers GSH, SOD, and TBARS in kidney and liver tissue, according to our findings. The TCDD group had significantly higher TBARS levels in the liver and kidney tissues than the CONTROL group; however, SOD and GSH levels were noticeably lower. In contrast to the TCDD group, the TCDD+TAU group had significantly lower TBARS levels, while GSH and SOD levels were higher. Similar to our results, it has been reported that TCDD significantly increased lipid peroxidation and decreased antioxidant activities, and that melatonin treatment significantly protected subjects from TCDD-induced cardiotoxicity in rats [34]. It has been shown that taurine treatment protected against oxidative damage in erythrocytes of tertiary butyl hydroperoxide-exposed mice by increasing GSH levels and decreasing

MDA and ROS levels [35]. Taurine's ability to reduce oxidative stress has also been reported in male albino rats with testicular dysfunction [36].

Our histopathological findings on the effects of TCDD in the tissues were consistent with biochemical results. Vascular congestion, apoptotic cells in the vena centralis, and eosinophilic stained pyknotic nuclei cells in the liver tissues have all been observed in rats exposed to TCDD. In addition, epithelial atrophy and cell desquamation, mononuclear cell infiltration, hemorrhage between the tubules, tubular lumen dilatation, casts in the tubular lumen, and glomerular degeneration in the kidney tissues. Taurine significantly reduced the severity of histopathological changes in the liver and kidney tissues when compared to the TCDD exposure group. Similarly, it has been shown that TCDD causes histopathological changes in the liver [37] and kidney [38], and reducing oxidative stress with antioxidant substances including beta-glucan and thymoquinone has been reported to have curative effects. Taurine has been shown to reverse caspase-3 activity as well as histological damage in treated rats' brain, testis, and epididymis [39]. Apoptotic cells were identified in this study using the immunohistochemical method. Taurine treatment inhibited Caspase-3 activity, according to immunoblotting analysis. Caspase-3-positive cells were not found in either the CONTROL or TAU groups' kidney or liver tissues. Taurine not only reduced histopathological damage but also the number of apoptotic cells, confirming Taurine's ability to reduce the toxic effects of TCDD. Previous studies found that taurine administration significantly reduced tissue damage and the number of apoptotic cells by suppressing increased oxidative stress via its antioxidant effect [40,41].

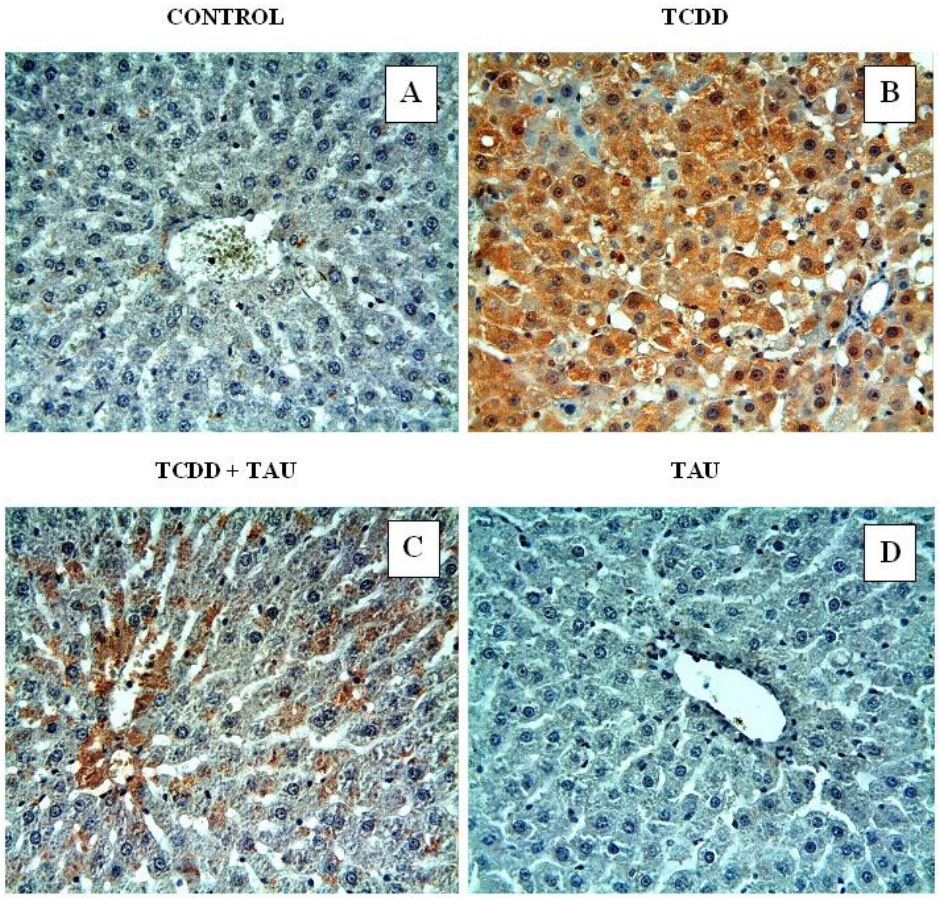

Figure 9. Liver tissue immunostaining for Caspase-3. In the CONTROL (A) and TAU (D) groups, no positively stained cells were observed. In TCDD (B) and TCDD + TAU (C) groups, Caspase-3 positive stained cells were observed. In TCDD + TAU group, positive stained cells were decreased compared with TCDD group (A-D: X40).

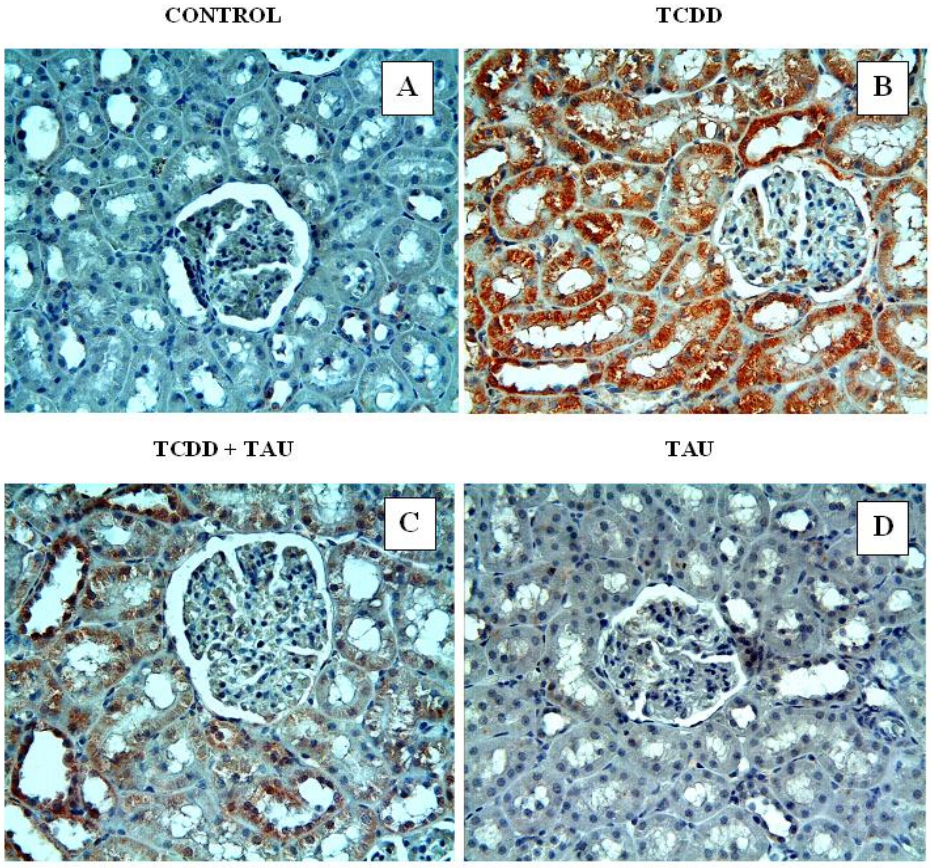

Figure 10. Kidney tissue immunostaining for Caspase-3. There were no positive stained cells in CONTROL (A) and TAU (D) groups. In TCDD (B) and TCDD + TAU (C) groups, Caspase-3 positive stained cells were observed. Positive stained cells were decreased in the TCDD + TAU group compared to the TCDD group (A-D: X40).

Table 2. Intensity of Caspase-3 positive staining score in liver tissue (Mean ± SE).

Groups	Caspase-3 positive staining score
CONTROL	$0.43 \pm 0.07^{*}$
TCDD	$16.7 \pm 0.86^{\#}$
TCDD + TAU	$10.4 \pm 0.39^{+}$
TAU	$1.15 \pm 0.17^{*}$

The mean differences between values with different superscripts in the same column were statistically significant (n=8) ($p \leq 0.001$). The mean differences between values with the same superscript in the same column were not statistically significant (n=8) ($p > 0.05$). *, #, and + superscripts indicate statistical significance of Caspase-3 positive staining score in liver tissue. Each value is mean ± standard error of the mean.

Table 3. Intensity of Caspase-3 positive staining score in kidney tissue (Mean ± SE).

GROUPS	Caspase-3 positive staining score
CONTROL	$0.78 \pm 0.10^{*}$
TCDD	$17.6 \pm 1.06^{\#}$
TCDD + TAU	$10.8 \pm 0.75^{+}$
TAU	$1.92 \pm 0.20^{*}$

The mean differences between values with different superscripts in the same column were statistically significant (n=8) ($p \leq 0.001$). The mean differences between values with the same superscript in the same column were not statistically significant (n=8) ($p > 0.05$). *, #, and + superscripts indicate statistical significance of Caspase-3 positive staining score in kidney tissue. Each value is mean ± standard error of the mean.

In conclusion, our findings show that taurine supplementation markedly reduces liver and kidney damage in male rats exposed to TCDD, improving both oxidative imbalance and histopathological alterations. Taurine supplementation could be used as an adjunctive therapy in the presence of TCDD toxicity due to its ability to reduce oxidative stress and apoptosis in liver and kidney organ damage caused by TCDD.

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AUTHOR CONTRIBUTIONS

Concept: M.F.D., O.Ç.; Design: M.F.D., O.Ç.; Control: O.Ç., B.Ç.; Sources O.Ç., N.B.T.; Materials: N.B.T., A.T.; Data Collection and/or Processing: M.F.D., M.N.Z.; Analysis and/or Interpretation: N.B.T., A.T., B.Ç.; Literature Review: A.T., B.Ç.; Manuscript Writing: M.F.D., M.N.Z.; Critical Review: M.F.D., O.Ç., N.B.T., A.T.; Other: -

CONFLICT OF INTEREST

The authors declare that there is no real, potential, or perceived conflict of interest for this article.

ETHICS COMMITTEE APPROVAL

Ethics committee approval was obtained from Pamukkale University Animal Experiments Ethics Committee on 13.01.2022 (Protocol no. PAUHDEK-2021/50).

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