

ORIGINAL ARTICLE

Histopathological Patterns of Renal Injury in Gentamicin-Exposed Wistar Rats Following Turmeric Essential Oil and Losartan Treatment

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ABSTRACT

Introduction: Gentamicin-induced nephrotoxicity is characterized by proximal tubular degeneration, necrosis, inflammatory infiltration, vascular congestion, and interstitial changes. Turmeric-derived preparations and losartan have been investigated as potential modifiers of renal injury, although direct histopathological evidence concerning turmeric essential oil remains limited. **Aim:** To describe and compare renal histopathological patterns in gentamicin-exposed Wistar rats treated with turmeric essential oil or losartan. **Methods & Materials:** This experimental animal study was conducted at the Department of Pharmacology and Therapeutics, Sir Salimullah Medical College, Dhaka, Bangladesh, from July 2019 to June 2020. Twenty-five adult male Wistar rats were randomly allocated to five groups of five animals. Group A received normal saline. Group B received gentamicin 80 mg/kg/day intraperitoneally on days 8–14. Groups C and D received turmeric essential oil at 50 and 100 mg/kg/day orally, respectively, for 14 days, together with gentamicin on days 8–14. Group E received losartan 10 mg/kg/day orally for 14 days, together with gentamicin on days 8–14. Renal sections were stained with haematoxylin and eosin and assessed for inflammatory-cell infiltration, vascular congestion, proximal tubular injury, epithelial regeneration, and interstitial vacuolation using ordinal grades from 0 to 4. **Results:** The gentamicin-treated group showed inflammatory-cell infiltration grade 4, vascular congestion grade 3, proximal tubular injury grade 3, and interstitial vacuolation grade 2. Tubular necrosis and desquamation involved more than 50% of proximal tubules, and regeneration was absent. With turmeric essential oil at 50 mg/kg/day, inflammation was grade 2, while congestion, tubular injury, and vacuolation were grade 1. With turmeric essential oil at 100 mg/kg/day and losartan, all four injury domains were grade 1. Tubular epithelial regeneration was present in all three intervention groups. **Conclusion:** Turmeric essential oil and losartan were associated with lower renal histopathological lesion grades than gentamicin alone. The findings were descriptive and did not establish statistical superiority or equivalence between treatments.

Keywords: Gentamicin Nephrotoxicity; Turmeric Essential Oil; Losartan; Renal Histopathology; Wistar Rats

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INTRODUCTION

Despite its recognized nephrotoxicity, gentamicin remains widely used against serious Gram-negative infections because of its rapid bactericidal activity, clinical familiarity, and relatively low cost. Following glomerular filtration, gentamicin is taken up preferentially by proximal tubular epithelial cells, where intracellular accumulation is associated with lysosomal dysfunction, mitochondrial injury, reactive oxygen species generation, inflammatory signalling, apoptosis, and necrosis [1]. Structurally, gentamicin-associated injury is expressed predominantly in the renal cortex and includes tubular epithelial swelling, vacuolation, degeneration, desquamation, necrosis, luminal cellular debris, interstitial inflammatory-cell infiltration, vascular congestion, and subsequent regenerative activity. In Wistar rats, progressive cortical tubular degeneration, necrosis, cytolysis, desquamation, mesangial alterations, and capillary congestion were observed with

increasing gentamicin dose and duration [2]. Likewise, progression from focal inflammatory-cell collections and tubular basophilia to more evident degeneration, necrosis, casts, and interstitial inflammation was documented after repeated gentamicin exposure [3]. More recently, tubular degeneration, necrosis, inflammatory infiltration, congestion, and interstitial changes have continued to be used as principal structural indicators of gentamicin-associated injury, often alongside molecular and urinary biomarkers [4,5]. Consequently, histopathological examination provides direct evidence of lesion location, type, and severity and remains central to the evaluation of structural renal injury. Unlike isolated serum measurements, tissue examination can distinguish predominantly tubular, interstitial, vascular, or glomerular involvement and can document coexisting degeneration and regeneration within the same experimental model. Because oxidative stress and inflammation are closely associated with

gentamicin-induced tubular damage, turmeric-derived preparations have been investigated as potential modifiers of renal tissue injury. Following turmeric administration in gentamicin-exposed rats, lower histopathological injury grades and less severe tissue disruption were reported than with gentamicin alone [6]. Similarly, reductions in tubular degeneration, necrosis, inflammatory abnormalities, and apoptosis were observed with curcumin treatment in experimental gentamicin nephrotoxicity [7]. Additionally, mitochondrial integrity was preserved, and gentamicin-induced renal cortical injury was attenuated following curcumin administration [8]. More recently, conventional and liposomal curcumin were both associated with improved renal cytoarchitecture, while formulation-dependent differences in histopathological protection were identified [9]. Furthermore, dose-related reductions in renal injury, oxidative stress, endoplasmic reticulum stress, and apoptosis were reported with curcumin pretreatment, although incremental benefits became smaller at higher doses [10]. Nevertheless, turmeric essential oil is chemically distinct from whole turmeric and curcumin-rich preparations. Within the oil, volatile sesquiterpenes, particularly α -turmerone, β -turmerone, predominate, whereas curcuminoids are generally absent or present only in negligible quantities [11]. In a cadmium-induced rat model, turmeric essential oil was associated with improved renal-function indicators and modulation of inflammatory cytokines, supporting possible renal activity of the oil itself, although gentamicin-associated renal histopathology was not examined [12]. Alongside botanical interventions, losartan has been evaluated as a pharmacological comparator. Reduced renal damage was reported when losartan at 10 mg/kg/day was administered with gentamicin at 80 mg/kg/day, whereas worsening nephrotoxicity was reported with a substantially higher losartan dose [13,14]. Thus, evidence concerning losartan appears dependent on dose and experimental conditions. Given the limited preparation-specific evidence for turmeric essential oil and the scarcity of direct histopathological comparisons with losartan, the present study described renal lesion patterns across normal control, gentamicin-exposed, turmeric-essential-oil-treated, and losartan-treated Wistar rats.

METHODS & MATERIALS

Study design and setting

Between July 2019 and June 2020, a controlled experimental animal study was conducted in the Department of Pharmacology and Therapeutics, Sir Salimullah Medical College, Dhaka, in collaboration with the Institute of Nutrition and Food Science, University of Dhaka. Ethical approval was obtained from the Institutional Ethics Committee of Sir Salimullah Medical College, Dhaka.

Experimental animals and sample size

A total of 25 healthy adult male Wistar albino rats (*Rattus norvegicus*), aged approximately 10–12 weeks and weighing 150–200 g, were obtained from the animal house of the Department of Pharmacology, Bangabandhu Sheikh Mujib Medical University, Dhaka. By applying the resource-equation method, the error degrees of freedom were calculated as $E=N-G=25-5=20$, where N represented the total number of animals and G represented the number of experimental groups. Following a seven-day acclimatization period, the animals were randomly allocated to five groups of five rats each.

Throughout the experiment, the rats were maintained in labelled metallic cages measuring approximately 38×23×15 cm, with each experimental group housed separately. Under a 12-hour light and 12-hour dark cycle, the animal room was maintained at approximately 26–28°C. Standard laboratory feed and drinking water were provided ad libitum. Regular cage cleaning, waste removal, and daily observation were undertaken throughout the study.

Preparation of turmeric essential oil

Fresh turmeric (*Curcuma longa*) rhizomes were collected locally and authenticated by the Institute of Nutrition and Food Science, University of Dhaka. After washing, surface drying, and slicing, 500 g of rhizomes were mixed with 1 L of distilled water and subjected to hydrodistillation at approximately 105°C for four hours. Subsequently, the essential oil was separated from the upper layer of the distillate, transferred to a tightly sealed amber bottle, and stored in a dark place until administration.

Experimental interventions

All oral interventions were administered once daily through an orogastric tube. To induce renal injury, gentamicin was administered intraperitoneally at 80 mg/kg/day from days 8 to 14 in Groups B, C, D, and E. Details of the experimental groups and treatment schedules are presented in (Table I).

Table I: Distribution of experimental rats and treatment schedule

Group	Experimental designation	n	Treatment during days 1–7	Treatment during days 8–14
A	Normal control	5	Normal saline, 20 mL/kg/day orally	Normal saline, 20 mL/kg/day orally
B	Gentamicin-treated control	5	No active treatment	Gentamicin, 80 mg/kg/day intraperitoneally
C	Turmeric essential oil, 50 mg/kg group	5	Turmeric essential oil, 50 mg/kg/day orally	Turmeric essential oil, 50 mg/kg/day orally, plus gentamicin, 80 mg/kg/day intraperitoneally
D	Turmeric essential oil, 100 mg/kg group	5	Turmeric essential oil, 100 mg/kg/day orally	Turmeric essential oil, 100 mg/kg/day orally, plus gentamicin, 80 mg/kg/day intraperitoneally
E	Losartan-treated group	5	Losartan, 10 mg/kg/day orally	Losartan, 10 mg/kg/day orally, plus gentamicin, 80 mg/kg/day intraperitoneally

All animals received standard laboratory feed and drinking water throughout the 14-day experimental period.

Kidney collection and tissue processing

On day 15, the animals were anaesthetised with chloroform and sacrificed by cervical dislocation. Following dissection, the kidneys were collected for histopathological examination. From three transverse levels of each kidney, tissue blocks measuring approximately 1×1×0.25 cm were obtained and fixed overnight in 10% formalin, using a fixative volume approximately 15–20 times the tissue volume. After fixation, dehydration was performed through ascending concentrations

of ethanol from 70% to 100%, followed by clearing in xylene. Paraffin infiltration was conducted at approximately 60°C, after which the tissues were embedded in paraffin wax. Using a rotary microtome, sections of approximately 6 μ m thickness were prepared, floated in a water bath at 48–50°C, mounted on adhesive-coated glass slides, and dried in a hot-air oven. Following deparaffinization and rehydration, the sections were stained with Harris haematoxylin and eosin. After dehydration and clearing, permanent mounting was performed using

dibutyl phthalate polystyrene xylene mounting medium and coverslips.

Histopathological evaluation

Using a five-headed Olympus microscope, stained renal sections were examined at low and high magnification, including 100× and 400×. During microscopic assessment, attention was given to inflammatory-cell infiltration, vascular congestion, proximal tubular epithelial degeneration or necrosis, tubular epithelial regeneration, and interstitial vacuolation. Necrotic cells were identified by increased cytoplasmic eosinophilia and nuclear changes including pyknosis, karyorrhexis, or karyolysis. Recorded lesion severity was expressed using an ordinal scale ranging from grade 0 to grade 4: grade 0, absent; grade 1, mild or focal; grade 2, moderate; grade 3, marked; and grade 4, severe or diffuse. Proximal tubular injury was categorized as grade 0 for normal tissue, grade 1 for focal epithelial degeneration involving less than 1% of the tubular population, grade 2 for necrosis or desquamation involving less than half of the cortical tubules,

grade 3 for necrosis or desquamation involving more than half of the proximal tubules, and grade 4 for complete or nearly complete tubular necrosis. Representative sections from each group were photographed at 100× magnification.

Data analysis

Histopathological findings were summarized descriptively according to the recorded ordinal grades and morphological patterns. Because the available histopathological records provided group-level lesion grades rather than individual-animal scores, no inferential statistical comparison was performed for these outcomes.

RESULTS

Renal sections from the five experimental groups were evaluated for five histopathological domains: inflammatory-cell infiltration, vascular congestion, proximal tubular injury, tubular epithelial regeneration, and interstitial vacuolation. The group-level lesion grades are presented in *Table II*.

Table II: Histopathological renal lesion profile across the experimental groups

Histopathological feature	Group A, n=5	Group B, n=5	Group C, n=5	Group D, n=5	Group E, n=5
Inflammatory-cell infiltration, grade	0	4	2	1	1
Vascular congestion, grade	1	3	1	1	1
Proximal tubular injury, grade	0	3	1	1	1
Tubular epithelial regeneration	Absent	Absent	Present	Present	Present
Interstitial vacuolation, grade	0	2	1	1	1

Grades: 0, absent or normal; 1, mild or focal; 2, moderate; 3, marked; 4, severe or diffuse. Group A, normal control; Group B, gentamicin-treated control; Group C, turmeric essential oil 50 mg/kg/day plus gentamicin; Group D, turmeric essential oil 100 mg/kg/day plus gentamicin; Group E, losartan 10 mg/kg/day plus gentamicin.

Within Group A, four of the five evaluated lesion domains were absent. Inflammatory-cell infiltration, proximal tubular injury, interstitial vacuolation, and epithelial regeneration were not observed, while mild vascular congestion was recorded at grade 1. The renal sections otherwise showed preserved glomerular and tubular architecture.

Within Group B, abnormalities were recorded in four of the five lesion domains. Severe inflammatory-cell infiltration was graded 4, marked vascular congestion was graded 3, and moderate interstitial vacuolation was graded 2. Proximal tubular injury was graded 3, with desquamation and necrosis involving more than 50% of the proximal tubules. No focal tubular epithelial regeneration was observed.

Compared with Group B, lower lesion grades were recorded in all three intervention groups. Within Group C, inflammatory-cell infiltration was graded 2, while vascular congestion, proximal tubular injury, and interstitial vacuolation were each graded 1. Focal tubular degeneration was present, and tubular epithelial regeneration was observed.

Within Group D, all four recorded injury domains were graded 1. Mild inflammatory-cell infiltration, vascular congestion,

interstitial vacuolation, and focal tubular degeneration were observed, together with focal regeneration of the tubular epithelium. Compared with Group C, inflammatory-cell infiltration was one grade lower in Group D, while the remaining recorded lesion grades were identical.

Within Group E, inflammatory-cell infiltration, vascular congestion, proximal tubular injury, and interstitial vacuolation were each graded 1. Focal tubular degeneration and focal epithelial regeneration were also observed. The lesion-grade profile in Group E was identical to that of Group D and differed from Group C only in the inflammatory-cell infiltration grade.

Across the intervention groups, proximal tubular injury declined from grade 3 in Group B to grade 1 in Groups C, D, and E. Vascular congestion declined from grade 3 to grade 1, while interstitial vacuolation declined from grade 2 to grade 1. Inflammatory-cell infiltration declined from grade 4 in Group B to grade 2 in Group C and grade 1 in Groups D and E. Tubular epithelial regeneration was present in all three intervention groups but absent in Groups A and B.

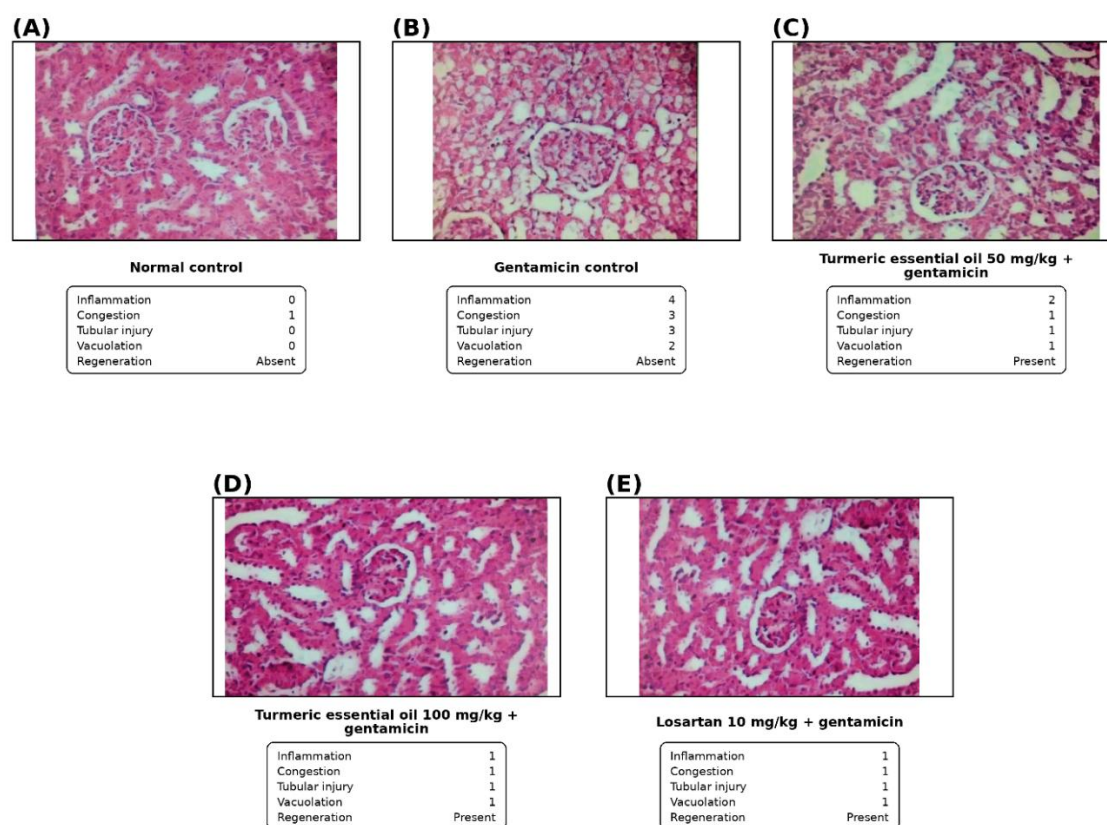


Figure 1. Representative H&E-stained renal sections from the experimental groups, 100× magnification.

Figure 1: Representative haematoxylin-and-eosin-stained renal sections from the experimental groups at 100× magnification.

A) Group A, normal control, showing preserved glomerular and tubular architecture, with mild vascular congestion. (B) Group B, gentamicin-treated control, showing severe inflammatory-cell infiltration, marked vascular congestion, proximal tubular desquamation and necrosis involving more than half of the tubules, and moderate interstitial vacuolation. (C) Group C, turmeric essential oil 50 mg/kg/day plus gentamicin, showing moderate inflammatory-cell infiltration, mild vascular congestion, focal tubular degeneration, mild interstitial vacuolation, and focal tubular epithelial regeneration. (D) Group D, turmeric essential oil 100 mg/kg/day plus gentamicin, showing mild inflammatory-cell infiltration, vascular congestion, focal tubular degeneration, interstitial vacuolation, and focal tubular epithelial regeneration. (E) Group E, losartan 10 mg/kg/day plus gentamicin, showing mild inflammatory-cell infiltration, vascular congestion, focal tubular degeneration, interstitial vacuolation, and focal tubular epithelial regeneration.

DISCUSSION

In the present study, gentamicin exposure produced the most pronounced renal histopathological pattern among the five groups. Severe inflammatory-cell infiltration was recorded at grade 4, vascular congestion and proximal tubular injury at grade 3, and interstitial vacuolation at grade 2. Tubular desquamation and necrosis involved more than 50% of the proximal tubules, without observable epithelial regeneration. Conversely, both turmeric essential oil doses and losartan were associated with lower lesion grades. Proximal tubular injury and vascular congestion declined to grade 1 in all intervention

groups, while regeneration was present. Inflammatory infiltration was grade 2 with turmeric essential oil at 50 mg/kg/day and grade 1 with turmeric essential oil at 100 mg/kg/day and losartan at 10 mg/kg/day. Consistent with previous experimental models, the gentamicin-treated control group showed a predominantly tubular and interstitial pattern of injury. Alarifi et al. observed cortical tubular degeneration, epithelial desquamation, necrosis, cytolysis, and capillary congestion following gentamicin exposure, with greater damage at higher doses and longer exposure periods [2]. Similarly, Udupa and Prakash documented tubular degeneration, necrosis, luminal cellular debris, casts, and interstitial inflammatory infiltration [3]. These observations correspond to the severe inflammation, marked congestion, tubular destruction, and vacuolation recorded in the present study. In addition, Tomşa et al. reported a median acute tubular necrosis score of 3 and a tubulointerstitial inflammatory score of 2 in gentamicin-exposed rats [15]. Although their scoring definitions differed, the numerical pattern was similar to the present tubular injury grade of 3 and vacuolation grade of 2. More recently, extensive proximal and distal tubular destruction, cytoplasmic vacuolation, interstitial oedema, leukocytic infiltration, and loss of tubular organization were observed following gentamicin administration by Ahmed et al [16]. Together, these comparisons indicate that the gentamicin group developed a characteristic and reproducible nephrotoxic lesion pattern. Following turmeric essential oil at 50 mg/kg/day, inflammatory infiltration decreased from grade 4 to grade 2, while congestion, tubular injury, and vacuolation decreased to grade 1. At 100 mg/kg/day, all four injury

domains were grade 1. These findings are directionally consistent with studies of whole turmeric and curcumin. Jogdand et al. reported a gentamicin-only histopathological grade of 3.66 ± 0.24 and a substantially lower grade of 0.60 ± 0.06 among turmeric-pretreated rats [6]. Likewise, Mahmoud et al. observed reductions in tubular degeneration, necrosis, vacuolation, epithelial desquamation, and inflammatory abnormalities following curcumin administration [7]. Bulboacă et al. also found fewer irreversible tubular lesions after conventional or liposomal curcumin treatment, although residual vacuolar and granular degeneration remained [9]. Such residual abnormalities resemble the mild focal lesions retained in the present intervention groups. Nevertheless, not every curcumin study demonstrated a corresponding reduction in tubular necrosis. In the study by Tomşa et al., curcumin reduced the median total lesion score from 7 to 5.5 and the tubulointerstitial infiltration score from 2 to 1, but the acute tubular necrosis score remained 3 in both the gentamicin and curcumin groups [15]. This differs from the present reduction in proximal tubular injury from grade 3 to grade 1 after turmeric essential oil administration. Variation in preparation is a likely consideration because turmeric essential oil contains volatile constituents and is not equivalent to purified curcumin. Other possible explanations include differences in gentamicin dose, pretreatment duration, animal characteristics, tissue sampling, and lesion definitions. Although inflammatory infiltration was one grade lower with turmeric essential oil at 100 mg/kg/day than at 50 mg/kg/day, the remaining lesion grades were identical. Therefore, the findings do not demonstrate a generalized dose-response relationship. At most, they indicate descriptively lower inflammatory involvement at the higher dose. Similarly, the presence of epithelial regeneration in both turmeric essential oil groups indicates concurrent reparative activity, but it does not establish that regeneration was caused exclusively by treatment. Previous studies have described restored tubular organization after curcumin treatment, including improved glomerular and tubular integrity in the study by Ahmed et al [16]. However, regeneration was rarely assessed as a separately defined outcome, and spontaneous repair after withdrawal or reduction of renal injury may also contribute.

Within the losartan group, inflammatory infiltration, congestion, proximal tubular injury, and vacuolation were each grade 1, while epithelial regeneration was present. This result agrees with Kourkinejad Gharaei et al., who used gentamicin at 80 mg/kg/day and losartan at 10 mg/kg/day and reported reduced overall renal damage, serum urea, creatinine, and renal oxidative injury [13]. However, conflicting findings were reported by Rizwan et al. In their Sprague-Dawley rat model, losartan at 15 mg/kg/day aggravated protein casts, calcification, tubular necrosis, inflammation, and renal tissue injury [17]. Poor Moosavi et al. also reported worsening biochemical nephrotoxicity when losartan was administered at 80 mg/kg/day, although histopathological findings were not assessed [14]. These differences suggest that the renal response to losartan may depend on dose, animal strain, treatment duration, haemodynamic conditions, and the timing of administration relative to gentamicin exposure. Notably, turmeric essential oil at 100 mg/kg/day and losartan at 10 mg/kg/day produced identical recorded group-level profiles: grade 1 for all four injury domains, with regeneration present. This observation does not demonstrate equivalence because individual-animal scores, variability estimates, confidence intervals, and equivalence testing were unavailable. Moreover, the histopathological data were summarized at group level, preventing inferential statistical comparison. Consequently,

the findings support descriptive differences in lesion patterns but cannot establish treatment superiority or equal efficacy. Despite these constraints, the consistent reduction from severe or marked lesions in the gentamicin group to predominantly mild focal abnormalities in the intervention groups provides morphological evidence that both turmeric essential oil and losartan were associated with less extensive renal tissue injury.

LIMITATIONS

Histopathological findings were available as group-level ordinal grades rather than individual-animal scores, which prevented estimation of within-group variability and inferential statistical comparison. In addition, lesion assessment was based on conventional haematoxylin-and-eosin staining without immunohistochemical or molecular markers, and the small sample size limited the strength of treatment comparisons.

CONCLUSION

Gentamicin exposure produced severe inflammatory-cell infiltration, marked vascular congestion, extensive proximal tubular injury, and moderate interstitial vacuolation in Wistar rats. Treatment with turmeric essential oil at 50 or 100 mg/kg/day and losartan at 10 mg/kg/day was associated with predominantly mild or focal renal lesions and the presence of tubular epithelial regeneration. The 100 mg/kg turmeric essential oil and losartan groups showed identical recorded lesion profiles, while the 50 mg/kg turmeric essential oil group retained moderate inflammatory infiltration. Because the findings were based on group-level descriptive grades, they indicate lower histopathological injury but do not establish statistical equivalence or treatment superiority.

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CONFLICT OF INTEREST

None declared

ETHICAL APPROVAL

The study was approved by the Institutional Ethics Committee

REFERENCES

1. Randjelovic P, Veljkovic S, Stojiljkovic N, Sokolovic D, Ilic I. Gentamicin nephrotoxicity in animals: Current knowledge and future perspectives. *EXCLI J.* 2017;16:388–99. doi:10.17179/excli2017-165 PubMed PMID: 28507482; PubMed Central PMCID: PMC5427480.
2. Alarifi S, Al-Doaiss A, Alkahtani S, Al-Farraj SA, Al-Eissa MS, Al-Dahmash B, et al. Blood chemical changes and renal histological alterations induced by gentamicin in rats. *Saudi J Biol Sci.* 2012 Jan;19(1):103–10. doi:10.1016/j.sjbs.2011.11.002 PubMed PMID: 23961168; PubMed Central PMCID: PMC3730558.
3. Udupa V, Prakash V. Gentamicin induced acute renal damage and its evaluation using urinary biomarkers in rats. *Toxicol Rep.* 2019;6:91–9. doi:10.1016/j.toxrep.2018.11.015 PubMed PMID: 30581763; PubMed Central PMCID: PMC6297903.
4. Balaha MF, Alamer AA, Eisa AA, Aljohani HM. Shikonin Alleviates Gentamicin-Induced Renal Injury in Rats by Targeting Renal Endocytosis, SIRT1/Nrf2/HO-1, TLR-4/NF-κB/MAPK, and PI3K/Akt Cascades. *Antibiotics.* 2023 May;12(5):826. doi:10.3390/antibiotics12050826
5. Dik B, Hatipoglu D, Ates MB. Potential effects of Resatorvid and alpha lipoic acid on gentamicin-induced nephrotoxicity in rats. *Pharmacology Research & Perspectives.* 2024;12(4):e1222. doi:10.1002/prp2.1222
6. Jogdand SD, Shinde R, Sinha V, Chandrakar N. Nephroprotective effect of turmeric on oxidative stress, renal histopathology and toxicity induced by gentamicin. *International Journal of Basic &*

- Clinical Pharmacology*. 2017 May 23;6(6):1282–6. doi:10.18203/2319-2003.ijbcp20172028
7. Mahmoud AM, Ahmed OM, Galaly SR. Thymoquinone and curcumin attenuate gentamicin-induced renal oxidative stress, inflammation and apoptosis in rats. *EXCLI J*. 2014 Feb 13;13:98–110. PubMed PMID: 26417245; PubMed Central PMCID: PMC4464512.
8. Negrette-Guzmán M, García-Niño WR, Tapia E, Zazueta C, Huerta-Yepez S, León-Contreras JC, et al. Curcumin Attenuates Gentamicin-Induced Kidney Mitochondrial Alterations: Possible Role of a Mitochondrial Biogenesis Mechanism. *Evid Based Complement Alternat Med*. 2015;2015:917435. doi:10.1155/2015/917435 PubMed PMID: 26345660; PubMed Central PMCID: PMC4541007.
9. Bulboacă AE, Porfire A, Bolboacă SD, Nicula CA, Feștilă DG, Roman A, et al. Protective Effects of Liposomal Curcumin on Oxidative Stress/Antioxidant Imbalance, Metalloproteinases 2 and -9, Histological Changes and Renal Function in Experimental Nephrotoxicity Induced by Gentamicin. *Antioxidants*. 2021 Feb;10(2):325. doi:10.3390/antiox10020325
10. Laorodphun P, Cherngwell R, Panya A, Arjinajarn P. Curcumin protects rats against gentamicin-induced nephrotoxicity by amelioration of oxidative stress, endoplasmic reticulum stress and apoptosis. *Pharmaceutical Biology*. 2022 Dec 31;60(1):491–500. doi:10.1080/13880209.2022.2037663 PubMed PMID: 35188833.
11. Orellana-Paucar AM, Machado-Orellana MG. Pharmacological Profile, Bioactivities, and Safety of Turmeric Oil. *Molecules*. 2022 Jan;27(16):5055. doi:10.3390/molecules27165055
12. Akinyemi AJ, Faboya OL, Paul AA, Olayide I, Faboya OA, Oluwasola TA. Nephroprotective Effect of Essential Oils from Ginger (*Zingiber officinale*) and Turmeric (*Curcuma longa*) Rhizomes against Cadmium-induced Nephrotoxicity in Rats. *J Oleo Sci*. 2018;67(10):1339–45. doi:10.5650/jos.ess18115 PubMed PMID: 30305562.
13. Gharaei FK, Safari T, Niazi AA, Bujani MZ. Losartan and magnesium sulfate administration reduce gentamicin-induced nephrotoxicity in rat model. *J Nephropathol*. 2018 Aug 20;8(2):e16–e16. doi:10.15171/jnp.2019.16
14. Poormoosavi SM, Behmanesh MA, Najafzadeh H. Effect of cimetidine on gentamicin-losartan induced -nephrotoxicity in rats. *AJPP*. 2010 Jun 30;4(6):341–5. doi:10.5897/AJPP.9000108
15. Tomşa AM, Răchişan AL, Pandrea SL, Benea A, Uifălean A, Toma C, et al. Curcumin and Vitamin C Attenuate Gentamicin-Induced Nephrotoxicity by Modulating Distinctive Reactive Species. *Metabolites*. 2023 Jan;13(1):49. doi:10.3390/metabo13010049
16. Ahmed AS, Sabra MS, Shaltout ES, Abdelqader ZS. In vivo and molecular docking investigation of the novel anti-inflammatory and mitochondrial mechanisms underlying the renoprotective effects of resmetirom and curcumin in gentamicin-induced renal toxicity in rats. *BMC Nephrol*. 2026 Apr 13;27(1):241. doi:10.1186/s12882-026-04928-8
17. Rizwan F, Yesmine S, Banu SG, Chowdhury IA, Hasan R, Chatterjee TK. Renoprotective effects of stevia (*Stevia rebaudiana* Bertoni), amlodipine, valsartan, and losartan in gentamycin-induced nephrotoxicity in the rat model: Biochemical, hematological and histological approaches. *Toxicology Reports*. 2019 Jan 1;6:683–91. doi:10.1016/j.toxrep.2019.07.003