Protective Effect of Lactoferrin against Chromium Induced Adverse Renal Changes in Rats: Oxidative Stress Theory

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Introduction

Owing to their toxicological and physiological effects on the environment, heavy metals have become synonymous with industrial pollution. Heavy metals can be absorbed orally, by inhalation, or through the skin (Al-Othman et al., 2012). Among the toxic metals, Chromium (Cr) which is a naturally occurring heavy metal used for chrome plating, in the manufacture of dyes, steel, alloys and pigments, leather tanning and wood preserving. Via the effluent from these industries, chromium usually enters the environment. It is a significant cause of environmental contamination once it is released into the soil and water (El-Saad et al., 2010; Mishra and Bharagava, 2016). The most prevalent and stable forms of Cr in the environment are hexavalent.
Chromium [Cr (IV)] and the most toxic form of Cr (IV) is potassium dichromate (Wu et al., 2012; Mehany et al., 2013). Potassium Dichromate (PDC, K$_2$Cr$_2$O$_7$) is a crystalline ionic solid, with a bright red-orange hue, most widely used as an oxidising agent in different laboratory and industrial applications. PDC is used for washing, leather, photography and building applications (Navya et al., 2018). It is a strong oxidising agent showing a marked affinity to form many complexes with various biological ligands, including nucleic acids, when reduced to trivalent chromium (Cr$^{3+}$) by numerous cell metabolites (Calvello et al., 2016).

By inhibiting antioxidant enzymes and binding to antioxidant elements such as Glutathione (GSH), chromium has the ability to alter cellular functions, contributing to oxidative stress (Kart et al., 2016). Ingestion, dermal contact and inhalation are the most common exposure routes for chromium (Sun et al., 2015).

As an adverse consequence of chromium, kidney failure is often cited. In comparison to the lack of evidence for chromium-induced chronic renal disease, massive hexavalent chromium toxicity appears to cause Acute Tubular Necrosis (ATN) (Teklay, 2016). In the proximal convoluted tubule, chromium compounds are selectively accumulated where, following parenteral administration, they cause acute tubular necrosis in large doses. There is reason to assume, along with the discovery of tubular proteinuria in chromium workers that chromium contributes to the production of chronic renal failure (Teklay, 2016).

Lactoferrin (LF) is an 80 kDa member of the iron binding glycoprotein transferrin family that was first found in human milk (Yao et al., 2013). The human kidney production of LF has been identified (Åbrink et al., 2000). LF is expressed and secreted in the collecting tubules and it may be reabsorbed in the distal part of the tubules. In a highly ordered way, the kidney produces LF and only a small fraction of this protein is secreted into the urine. LF is also believed to have essential roles in both the urinary tract's immune response and in the metabolism of iron in general (Adlerova et al., 2008). The aim of the current study was to assess the biochemical and histopathological adverse effects of PDC on male rat kidneys. Also, to determine the potential protective effect of co-therapy with LF on adverse renal changes caused by PDC.

Materials and Methods

Chemicals

Potassium Dichromate (PDC) and lactoferrin were purchased from Sigma-Aldrich Company (St. Louis, MO, USA). All used reagents were of analytical grade and highest purity. The CAS numbers were 777-50-9 and 936541-36-5, respectively.

Animals and Treatment

In this study, 40 male albino Wister rats, 3-6 months of age, weighted 200±50 g were used. They were kept under a well-regulated light and dark (12 h: 12 h) schedule at 22-25°C. The animal had free access to tap water and treated according to the guidelines of the Animal House of South Valley University-Qena, where standard commercial pellets were used for feeding and water ad libitum. All experimental protocols were performed in accordance with the local institutional guidelines and approved by the Animal Ethical Committee, South Valley University-Qena, Egypt.

The included rats were divided randomly into 4 groups (n = 10 each). All treatments were administered single dose daily. All chemicals were dissolved in 1% Dimethyl Sulfoxide (DMSO) and rats were treated daily for 14 days as follow (Fig. 1):

- Group-I (control group): Received 1% DMSO orally.
- Group-II (LF group): Received lactoferrin (300 mg/kg) orally (Kimoto et al., 2013)
- Group-III (PDC group): Received potassium dichromate (15 mg/kg) Subcutaneous injection (Hegazy et al., 2016)
- Group-IV (PDC+LF): Received potassium dichromate (15 mg/kg) subcutaneous injection and lactoferrin (300 mg/kg) orally

Sample Collection

The animals were starved overnight at the end of the experimental phase (2 weeks) and anaesthetized using diethyl ether inhalation; then, at the time of scarification, the blood samples were collected from the retro-orbital veins into plain tubes and centrifuged for 10 min at 1000 g and the separated sera were split into aliquots in 1 mL cryotubes and preserved at -80°C until biochemical assays were carried out (Saleem et al., 2018; Hassan et al., 2020). The kidneys were dissected out immediately and cleaned of adhering tissues and were immersed in neutral buffered formalin10% for histopathology examination.

Biochemical Analysis

Serum urea, creatinine, glucose and Total Antioxidant capacity (TAO) measurements were performed, by colorimetric method (Chem-7, Erba Diagnostics Mannheim GmbH, Germany), using commercially available assay kits supplied by Spectrum Company, Egypt, for urea, creatinine and glucose, with catalog no. 318 001, 253 001 and 253 001 respectively. While, TAO kit was supplied by Biodiagnostics, Egypt (Saleem et al., 2018; Hassan et al., 2019; Saleem et al., 2020).
Histopathological Assessments

Using traditional paraffin-embedding methods, processing of the fixed renal tissues was carried out. Using a microtome, five µm thick parts were obtained from prepared paraffin blocks. Then, hematoxylin and eosin staining stained these parts (Gabe, 1976; Gamble, 2008), for examination by light microscope. Additionally, histological technique for semi-thin and ultrathin renal tissue sections were performed (Ayache et al., 2010), where semi thin sectioning at 1µm renal specimens were trimmed with a razor blade and stained with 2% aqueous toluidine blue then dried on a hot plate at 40°C and were examined by light microscope. While, ultrathin sectioning at 50 nm were recommended on cooper grids and were examined by a transmission JEOLJEM-100CX II electron microscope and were photographed.

Statistical Analysis

The statistical analyses were carried out using SPSS version 22.0 (IBM, Armonk, NY, USA). Data with normal distribution (according to Kolmogoroy-Snimov test) were analyzed by one-way Analysis Of Variance (ANOVA) followed by Turkey’s HSD post hoc test for comparison between multiple quantitative variables and were expressed as mean ± SD. Statistical significance was considered when p<0.05.

Results

Serum Biochemical Assessments and Antioxidant Status of Various Study Groups

Regarding to the biochemical evaluation of the kidney function among the study groups, there was statistically significant higher mean ± SD blood urea (mg/dl) and serum creatinine (mg/dl) among PDC-treated rats (group-III) (69.4±44.15 and 0.566±0.13 respectively) compared to both the control group (group-I) (45.2±7.44 and 0.492±0.07 respectively) and LF only-treated rats (group-II) (38.8±7.49 and 0.402±0.03 respectively), p<0.05 for all. Additionally, there were no significant differences between control group and PDC+LF treated rats (group-IV), p>0.05 for both, (Table1).

As regards serum random blood glucose (mg/dl), there was significantly higher mean levels ± SD among PDC-treated rats (group-III) (140.8±50.27) compared to both the control group (group-I) and LF only-treated rats (group-II) (113±15.23 and 110.8±27.95, respectively), p<0.05 for all. However, there was no significant difference in the serum glucose levels among control group compared to PDC+LF treated rats (group-IV), p>0.05, (Table1).

As regard the antioxidant status of the study groups, there were significant lower mean ± SD serum total antioxidant capacity (mmol/ml) among PDC-treated rats (group-III) (6.22±2.09) compared to each of the control group (group-I), LF only-treated rats (group-II) and PDC+LF treated rats (group-IV) (8±0.84, 8.02±1.05 and 7.94±1.53 respectively), p<0.05 for all. However, there was no significant difference in the serum TAO levels among control group compared to PDC+LF treated rats (group-IV), p>0.05, (Table1).

Histopathological Findings of the Rats’ Kidneys among the Various Study Groups

Regarding to control group and lactoferrin treated rats (group-I and II) using light microscopy (H&E and semithin sections toluidine blue), the histopathological renal examinations revealed normal renal parenchyma, normal appearance of glomerulus and mesangial cells, proximal convoluted tubule, distal convoluted tubules, Urinary (Bowman’s) space and vascular pole (Fig. 2A1-A2 and 3B1-B2).
Fig. 2: Histopathological findings of the kidneys of the study groups using light microscopy H&E (X 400). A1 and A2 represents photomicrograph of renal cortex from the control group (group I) and lactoferrin treated rat (group II) showing normal renal parenchyma: glomerulus (G), proximal convoluted tubule (P), distal convoluted tubules (D). Urinary (Bowman's) space (S) and vascular pole (arrow). A3-A9 represent histopathological findings of the kidneys of potassium dichromate-treated rats (group-III): A3: Photomicrograph of renal cortex showing intraluminal casts (long arrow), tubular degeneration (short arrow), dilated congested interstitial blood vessels (curved arrow), haemorrhagic hypercellular glomeruli (star) and inflammatory infiltrate (arrow head); A4: Photomicrograph of renal cortex showing tubular epithelial vacuolation (long arrow), nuclear pyknosis (arrow head) and binucleation (short arrow) and widened Bowman's space (star) surrounding shrunken glomeruli (curved arrow); A5: Photomicrograph of renal cortex showing tubular epithelial vacuolation (long arrow) and binucleation (short arrow), intraluminal eosinophilic casts (curved arrow) and interstitial hemorrhage (star); A6: Photomicrograph of renal cortex showing tubular epithelial vacuolation (long black arrow), intracytoplasmic hyaline droplets (open arrow), intraluminal casts (short blue arrow) pyknosis (arrow head) and binucleation (short black arrow), widened Bowman's space (star) surrounding atrophied glomeruli (curved arrow) and interstitial hemorrhage (long blue color); A7: Photomicrograph of renal cortex showing tubular epithelial hyperplasia (long arrow) and karyomegally (short arrow); A8: Photomicrograph of renal cortex showing necrotic shrunken (short arrow) and lobulated glomeruli (long arrow). A9: Photomicrograph of renal cortex showing capillary congestion of glomerular tuft (long arrow), inflammatory cells around renal corpuscle (open arrow) and moderate thickening of the basement membrane of Bowman’s capsule (short arrow). A10-A15 represent histopathological findings of the kidneys of potassium dichromate and lactoferrin co-treated rats (group-IV): A10: Photomicrograph of renal cortex showing mild glomerular damage (long arrow), with uniformly arranged regenerative renal tubules (short arrow); A11: Photomicrograph of renal cortex showing mild glomerular damage (long arrow) and mild damage of the tubular lining epithelium (short arrow); A12: Photomicrograph of renal cortex showing mild tubular damage, with granular damage of their lining epithelium (arrows); A13: Photomicrograph of renal cortex showing mild granular damage of the tubular lining epithelium (arrows); A14: Photomicrograph of renal cortex showing mild granular damage of the tubular lining epithelium (arrows); A15: Photomicrograph of renal cortex showing mild glomerular damage (arrows)
Fig. 3: Histopathological findings of the kidneys of the study groups using Semithin sections toluidine blue X1000. B1 and B2 represent photomicrographs of kidneys from the control group (group I) and lactoferrin treated rat (group II); B1: Photomicrograph showing normal appearance of glomerulus (long arrow), Bowman’s space (short arrow) and mesangial cells (open arrow) of the control/Lf-treated rats; B2: Photomicrograph showing normal appearance of proximal tubule (long arrow) and distal tubule (short arrow). B3-B5 represent photomicrographs of the kidneys of potassium dichromate-treated rats (group-III): B3: Photomicrograph showing necrotic shrunken and lobulated glomerulus with widened Bowman’s capsule (long arrow), some nuclei are dense (short arrow) while others appear pale (open arrow); B4: Photomicrograph showing proximal tubules with epithelial vaculations (short arrows) and intraluminal casts (long arrows); B5: Photomicrograph showing congestion of the blood vessels (long arrow) and interstitial inflammatory cells (short arrow). B6 and B7 represent photomicrographs of the kidneys of potassium dichromate and lactoferrin co-treated rats (group-IV): B6: Photomicrograph revealing PCT (long arrow) and DCT (short arrow) with more or less normal appearance; B7: Photomicrograph revealing more or less normal appearance of renal glomerulus with podocytes (long arrow), mesangial cells (short arrows) and capillaries (open arrow).

Table 1: Mean ± SD of blood urea, serum creatinine, random blood glucose and total antioxidant capacity levels among the study groups

<table>
<thead>
<tr>
<th>Biochemical parameters</th>
<th>Group-I (n = 10) Mean ± SD</th>
<th>Group-II Mean ± SD</th>
<th>Group-III Mean ± SD</th>
<th>Group-IV Mean ± SD</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Blood urea (mg/dl)</td>
<td>45.2±7.44±7.49</td>
<td>38.8±7.49</td>
<td>69.4±44.15</td>
<td>45.2±4.02</td>
<td>0.001*</td>
</tr>
<tr>
<td>Serum creatinine (mg/dl)</td>
<td>0.492±0.07±0.07</td>
<td>0.402±0.03</td>
<td>0.566±0.13</td>
<td>0.528±0.04</td>
<td>0.001*</td>
</tr>
<tr>
<td>Random blood glucose (mg/dl)</td>
<td>113±15.23±15.23</td>
<td>110.8±27.95±27.95</td>
<td>140.8±50.27±50.27</td>
<td>119±29.21±29.21</td>
<td>0.021*</td>
</tr>
<tr>
<td>Total antioxidant capacity</td>
<td>8±0.84±0.84</td>
<td>8.02±1.05</td>
<td>6.22±2.09±2.09</td>
<td>7.94±1.53±1.53</td>
<td>0.001*</td>
</tr>
</tbody>
</table>

* Statistically significant difference (p<0.05); Data presented in (mean ± SD) using ANOVA test for comparison; Group-I: Control group; Group-II: Lactoferrin group; Group-III: Potassium dichromate group; Group-IV: Potassium dichromate + lactoferrin group; a significant difference when comparing group-I Vs. group-II; b significant difference when comparing group-I Vs. group-III; c significant difference when comparing group-II Vs. group-III; d significant difference when comparing group-III Vs. group-IV. No significance differences between group-I and IV.

Using electron microscopy, the epithelial cells in a distal convoluted tubule of the control/Lf-treated rats revealed cells rest on the basement membrane and circumscribing the tubular lumen which is greatly reduced by the expanded blebs bulging into the lumen. Cells harbor a considerable number of elongated mitochondria with normal renal filtration barrier. Proximal tubule cells showed apical numerous microvilli (brush border), euchromatic rounded nucleus, some cytoplasmic vacuoles and mitochondria as presented in (Fig. 4C1-C5).
Fig. 4: Histopathological findings of the kidneys of the study groups using electron microscopy. C1-C5 represent photomicrographs of kidneys from the control group (group I) and lactoferrin treated rat (group II); C1: Epithelial cells in a distal convoluted tubule of the control/Lf-treated rats. Cells rest on the basement membrane (long arrow) and circumscribing the tubular lumen which is greatly reduced by the expanded blebs (short arrow) bulging into the lumen. Cells harbor a considerable number of elongated mitochondria (open arrow). (X 4300); C2: The kidney’s filtration barrier appeared normal consisting of glomerular basement membranes (long arrow), fenestrated endothelium (short arrows) and secondary foot processes (open arrows) separated by filtration slits (blue arrows) (X 5200); C3: The proximal tubule cells show apical numerous microvilli (brush border) (long arrow), euchromatic rounded nucleus (short arrow), lysosomes (open arrow), RER (blue arrow) and basal membrane invaginations associated with elongated mitochondria (curved arrows). (X 5800); C4: The proximal tubule cells show apical numerous microvilli (brush border) (long arrow), euchromatic rounded nucleus (short arrow), some cytoplasmic vacuoles (blue arrow) and mitochondria (curved arrows). (X 58000); C5: The interstitial space between two tubules that contain blood capillaries (long arrow), interstitial cells (short arrow) and mitochondria (open arrow). (X4800). C6-C9 represent photomicrographs of the kidneys of potassium dichromate-treated rats (group-III): The epithelial cells of the proximal tubule from the kidney cortex. Some mitochondria are swollen and many lysosomes (long arrows) are seen. Disintegrated microvilli (short arrows). A necrotic epithelial cell (open arrow) is seen with a pyknotic nucleus (blue arrow) (X 5000); C7: The epithelial cells of the proximal tubule from the kidney cortex. Some mitochondria are swollen (long arrows) and many lysosomes (short arrows) are seen. Disintegrated microvilli are demonstrated in the lumen (curved arrow). (X 5800); C8: The congested glomerular capillaries (long arrow) with irregularly thickened capillary basement membranes (short arrow), damaged podocytes (open arrow) having large intraluminal vacuoles (blue arrow) (X 4800); C9: Apparent increase in thickness of the basal lamina (long arrow) with partial loss of basal infoldings (short arrow). Mitochondria (open arrow) and condensed relatively dense nucleus (blue arrow). (X 4000).C10-C12 represent photomicrographs of the kidneys of potassium dichromate and lactoferrin co-treated rats (group-IV); C10: The proximal convoluted tubule cell showed restoration of the integrity of the apical brush border (long arrows), mitochondria more or less normal in shape and size (short arrows) and a few vacuoles (open arrow) are seen (X 4800); C11: Multiple basal mitochondria (long arrows) and restored basal infoldings (short arrows) and nucleus (open arrow). (X 4000); C12: The proximal tubule in the renal cortex showed normal ovoid nucleus (long arrow), mitochondria appeared rather normal in shape (short arrow), with little restored regular apical brush border (curved arrow), some vaculocations are still seen (blue arrow). (X 5800)
As regards the histopathological findings of the kidneys of potassium dichromate-treated rats (group-III), light microscopic examination revealed intraluminal casts, tubular degeneration and dilation, dilated congested interstitial blood vessels, hypercellular glomeruli with hemorrhage and interstitial inflammatory infiltrate with hemorrhagic blood masses of the renal cortex with degenerations in the tubular epithelial cells. Widened Bowman's space was surrounded atrophied and shrunken glomeruli (Fig. 2A3-A9 and Fig. 3B3-B5). An electron micrograph showed congested glomerular capillaries with irregularly thickened capillary basement membranes, damaged podocytes with large intraluminal vacuoles as presented in (Fig. 4C6-C9).

Regarding to the histopathologic effects from adding lactoferin co-therapy to PDC (group-IV), H&E and semithin toluidine blue sections revealed decreased glomerular damage with regeneration of the renal tubules with more or less normal podocytes, PCT and DCT (Fig. 2A10-A15 and 3B6-B7). Electron micrograph of the kidney showed restoration of the integrity of the apical brush border, mitochondria more or less normal in shape and size and a few vacuoles in the proximal convoluted tubular cells with mitochondria appeared rather normal in shape as presented in (Fig. 4C10-C12).

Discussion

The liver and kidney are the most important organs for the metabolism, detoxification, storage and excretion of xenobiotics and their metabolites and is particularly susceptible to multi-agent harm (Park et al., 2014). The kidney is the target organ of systemically absorbed chromate and in acute chromium exposure, nephrotoxicity or total renal shutdown may be the primary cause of death. The chromate's tubular damage and nephrotoxic effect resulted from its accumulation in vacuoles within the proximal tubular cells, resulting in slower excretion and long-term remaining of Cr in the kidney (Hegazy et al., 2016).

In this research, the adverse pathological effects of PDC on the kidneys of male rats and the beneficial effects of co-treatment with LF were evaluated.

In the current study, single dose PDC injection for 14 days (group-III) induced acute kidney injury in rats, as evidenced by significant renal function test alterations, confirmed by severe changes in PDC group histopathology, especially tubular necrosis. In the current research, the assessment of kidney functions was evaluated by estimating the levels of blood urea and serum creatinine. Compared to other groups, there was a statistically significant increase in levels of urea and creatinine in the PDC-treated group. This was in line with proven literature evidence of alteration of renal functions caused by Cr. The rise in these parameters was due to loss of functional integrity in the kidney and renal tubule distortion as a consequence of Cr administration (Venter et al., 2017). Many studies were in line with our findings and clarified that Cr-induced renal dysfunction could be due to Cr renal tubular damage and cell debris obstruction (Sahu et al., 2014; Hegazy et al., 2016).

In the current research, it was evident that, given the acute increase in blood glucose in the PDC treated group (group-III), the occurrence of renal function disorder was also recorded, our findings were in line with (El-Guendouz et al., 2020) results. Arreola-Mendoza et al., (2006) however, found that blood glucose in the PDC treated rats was not significantly elevated, though apparent glucosuria was reported and this was explained by the lack of absorption due to proximal tubular injury caused by this metal. The surprisingly toxic aspect of urea was illustrated by a study by Koppe and his colleagues. They proposed that urea is directly responsible for the impaired secretion of insulin in chronic kidney disease and a specific protein named phosphofructokinase-I was found in the pancreatic beta cells in their research. The function of this protein was modified by an increase in urea in the blood that occurred during kidney disease. Increased urea causes insulin release from the beta cells of the pancreas to be impaired. This induces oxidative stress and excessive phosphofructokinase-I glycosylation, which creates an imbalance of blood glucose and may contribute to diabetes (Koppe et al., 2016).

The kidney is the main route of excretion of Cr and acute exposure to PDC in rats has been reported to cause an increase in the content of Cr in the kidney. While Cr itself does not produce free radicals directly, it indirectly creates various radicals such as superoxide, peroxynitrite, nitric oxide and hydroxyl that cause damage consistent with oxidative stress (Mehany et al., 2013). Since the nephrotoxic effect of PDC is mainly due to oxidative stress caused by it, the present study evaluated TAO levels in the groups studied and showed a significant decrease in TAO levels in the serum of the PDC group (group-III). Such reports were in line with many investigators (Hegazy et al., 2016; El-Guendouz et al., 2020).

With regard to the effect of PDC on proximal convoluted tubules, tubular degeneration, dilation, intraluminal casting, nuclear pycnosis and binucleation and vacuolar formation of proximal convoluted tubules were shown in the present research. Similar findings were previously demonstrated by Hegazy et al., who revealed significant necrobiotic changes in almost proximal convoluted tubules and clarified that chromate's tubular damage and nephrotoxic effect resulted from its accumulation in vacuoles within the proximal tubular cells, leading to slow excretion and long-term retention of Cr in the kidney (Hegazy et al., 2016). They also stated that the treated animals showed intraluminal and intracytoplasmic accumulation of acidophilic hyaline and renal cast content (Hegazy et al., 2016). Also other studies...
showed similar findings (El-Mahalaway et al., 2015; Hanan et al., 2019).

The key intracellular source of ROS is mitochondria and they have a very efficient antioxidant system. The targets of metal toxicity are mitochondria. Oxidative stress results in dysfunction of the mitochondria and apoptosis (García-Niño et al., 2013). In the current research, electron microscopic analysis of group-III proximal and distal convoluted tubular cells showed a shrunken nucleus with chromatin margination (a sign of cell apoptosis). These results were in line with those of prior research (Abdel-Moneim and Said, 2007; Rashedy et al., 2013; Morya and Vachhrajani, 2014; El-Mahalaway et al., 2015).

To prevent the toxicities caused by chemicals, many natural products have been used to protect against such toxicities (Guo, 2017). Lactoferrin (LF, formerly known as lactotransferrin) is an iron-binding glycoprotein, belonging to the transferrin protein family, together with serum Transferrin (sTf), Ovotransferrin (Otrf), melanotransferrin and the inhibitor of carbonic anhydrase (González-Chávez et al., 2009). High levels of LF-mRNA and protein were found in the kidneys during screening for LF expression in different organs. This showed that LF is provided by the kidneys and that LF may have important functions in this organ’s intrinsic immunity as well as in the antioxidant and other kidney safety systems against any other non-microbial injuries, such as ischemia-reperfusion and inflammation (Abrink et al., 2010).

The current study also showed that the serum urea and creatinine levels in the LF-treated group (group-II) were statistically significantly reduced compared to the control group (group-I), in line with the reported vital function of LF for kidney health (Abrik et al., 2010). However, there was no statistical difference between control group (group-I) and PDC and LF-treated group (group-IV). Serum creatinine and urea levels were decreased in PDC and LF co-treated group (group-IV) denoting the importance of LF in restoration of kidney function induced by Cr-nephrotoxicity. LF suppressed oxidative stress-induced cell death and apoptosis in human kidney tubular epithelial cells, the latest study findings found. In addition, by suppressing expression of the profibrogenic genes CTGF, PAI-1 and collagen I, lactoferrin inhibited TGF-β1-induced renal fibrosis (Hsu et al., 2020).

In the current research, LF (group-IV) treatment of rats significantly protected the kidney against oxidative stress caused by PDC, as evidenced by the preservation of normal TAO. In line with this, (Kimoto et al., 2013) showed a protective effect of LF in rats against cisplatin-induced nephrotoxicity. In addition, several studies have recorded the antioxidant effect of LF and suggested that the binding of LF to cells limits the process of membrane lipid peroxidation, since LF is not entirely saturated and is capable of removing free iron radicals that are cytotoxic activators of lipid peroxidation and oxidative stress, thereby suppressing free radical harm (Latorre et al., 2010; Ogawara et al., 2014; Hessin et al., 2015; Hegazy et al., 2016).

The light microscopic photomicrographs obtained from the PDC+LF treated rats (group-IV) showed relative restoration of the normal renal architecture and reversion of most of the destructive changes showing mild glomerular damage, mild tubular damage, granular damage with uniformly organised regenerative renal tubules of their lining epithelium. These findings provide further evidence of the protective effect of LF against nephrotoxicity caused by metals in rats, in agreement with several investigators (Latorre et al., 2010; Kimoto et al., 2013; Ogawara et al., 2014; Hessin et al., 2015; Hegazy et al., 2016).

In addition, group-IV showed an increase in PDC-induced ultrastructural improvements, as evidenced by electron microscopic examination. The presence of mitotic tubular cell behaviour was indicative of regeneration of the tubular cells. In addition, the integrity of brush boundary, mitochondria and basal infolding were restored. In humans and laboratory animals, it has been documented that LF has a protective effect against several toxicants. It increases the resistance of the body to several harmful factors and protects tissues from damage, as well as decreases chromosomal aberrations caused by certain chemicals (Hsu et al., 2020).

Conclusion

The current study provides evidence of LF’s renoprotective role against PDC-induced renal damage by increasing antioxidant activity to restore chromium exposure-induced functional and structural renal damage.

Study Limitation

Lack of using multi-dose design (low, medium and high dose) of lactoferrin to evaluate the possible dose-effect relationship was the main limitation of the current study which could be designed in future researches.

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Authors’ Contributions

Mohammed H. Hassan: Study concept and design, experimental procedures, blood sampling and biochemical assays, statistical analysis, literature research, first manuscript drafting.

Dorreia Abd-Alla Mohamed Zaghloul: Study concept and design, experimental procedures, histopathological examinations, statistical analysis.
Marwa Ahmed Mahmoud and Rana Toghan: Experimental procedures, histopathological examinations, literature research.

Zamzam Nasrallah Abdel-Moaty: Experimental procedures, histopathological examinations, literature research, statistical analysis.

Ethics Approval

All experimental protocols were performed in accordance with the local institutional guidelines and approved by the Animal Ethical Committee, South Valley University-Qena, Egypt.

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