Immunolocalization of intermediate filaments in the kidney of the dromedary camel (*Camelus dromedarius*)

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SUMMARY

Intermediate filaments belong to a large family of proteins which contribute to the formation of the cytoskeleton. The immunolocalization of cytoskeletal proteins has been used extensively in the diagnosis of various renal pathologies. The present study described the immunolocalization of the cytoskeletal proteins vimentin, desmin, smooth muscle actin, and cytokeratin 19 in the normal kidney of the dromedary camel. Kidney samples from eight adult camels were processed for histology and immunohistochemistry. The kidney was enclosed in a renal capsule composed of vimentin immunoreactive fibroblasts and smooth muscle actin immunoreactive smooth muscle cells. The smooth muscle cells in the renal capsule did not exhibit desmin immunoreactivity. Podocytes forming the visceral layer of the glomerular capsule were immunoreactive for vimentin. Immunoreactivity for vimentin and smooth muscle actin in the parietal layer of the glomerular capsule varied, with both reactive and non-reactive cells observed. Intraglomerular mesangial cells were immunoreactive for smooth muscle actin and desmin, but non-reactive to vimentin. The endothelial lining of blood vessels was vimentin immunoreactive, while smooth muscle actin and desmin were demonstrated in the smooth muscle cells of the vessels. The thin limbs of the loops of Henle in cortical nephrons displayed vimentin immunoreactivity. The proximal and distal convoluted tubules, as well as the collecting ducts were negative to vimentin, smooth muscle actin, desmin and cytokeratin 19 immunostaining. In conclusion, the present study has revealed that similarities and differences exist in the immunolocalization of cytoskeletal proteins in the camel when compared to other mammals. The presence of smooth muscle actin in the parietal cells of the glomerular capsule suggests a contractile function of these cells. The results of the study indicate that vimentin and smooth muscle actin can be used as markers for the identification of podocytes and intraglomerular mesangial cells, respectively, in the camel kidney.

Key words: Immunohistochemistry – Vimentin – Desmin – Smooth muscle actin – Cytokeratin 19 – Camelid

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INTRODUCTION

Camels exist in arid and semi-arid environments, and are well-equipped with mechanisms which allow them to withstand sub-optimal environmental conditions, such as limited water resources (Drosa et al., 2011(. One of these mechanisms, which is the maintenance of electrolyte and water balance during dehydration and fast rehydration, is attributed to the kidney (Jararr and Faye, 2015). For a better understanding of this renal mechanism, several investigations have been carried out on the histology of the kidney in the dromedary camel (Abdalla and Abdalla, 1979; Safer et al., 1988; Eissa et al., 2018; Eissa et al., 2019, Abdalla, 2020). However, despite these studies, several histological features of the camel kidney remain unknown.

Intermediate filaments form a large family of proteins that contribute to the formation of most of the cytoskeleton (Block et al., 2015; Lowery et al., 2015). More than 50 different intermediate filament proteins have been identified (Cooper and Hausman, 2006). A knowledge of the various types of these proteins is useful in comparing and contrasting their structural and functional properties. In this respect, it is widely accepted that the main functions of intermediate filaments are related to the support of cellular physiological activities and structural integrity (Satelli and Li, 2011; Chernoivanenko et al., 2015; Lowery et al., 2015; Snider, 2016). Intermediate filaments can also improve the resistance of cells to various forms of stress and damage caused by pathological processes (Toivola et al., 2010; Battaglia et al., 2017).

Vimentin, desmin, smooth muscle actin and cytokeratin 19 are cytoskeletal proteins which are present in the kidneys of several mammalian species (Şen et al., 2010; Novakovic et al., 2012; Laszczyńska et al., 2012). However, their expression and distribution vary depending on the species and type of renal epithelial cell concerned (Şen et al., 2010). Vimentin is a specific marker for cells of mesenchymal origin (Yang et al., 2019). Smooth muscle actin and desmin have been used as markers for muscle differentiation (Rangdaeng and Truong, 1991). Desmin is found in all muscle types (Robson et al., 2004; Lowery et al., 2015), while smooth muscle actin is restricted to smooth muscle cells, pericytes, myoepithelial cells and myofibroblasts (Rangdaeng and Truong, 1991). Cytokeratins are considered the most abundant cytoskeletal components, with an extensive localization in epithelial cells of the kidney, liver, and lung (Bragulla and Homberger, 2009; Pastuszak et al., 2015; Djudjaj et al., 2016; Werner et al., 2020).

Several researchers have studied cytoskeletal proteins in normal and pathological kidneys of humans (Şen et al., 2010; Sharma et al., 2019), rats (Herrmann, et al., 2012; Funk, et al., 2016), dogs (Gil da Costa et al., 2011), and polar foxes (Laszczyńska, et al., 2012). These studies have shown that the expression and distribution of intermediate filaments varies depending on the type of renal cell, the pathological condition, as well as the animal species concerned (Şen et al., 2010; Laszczyńska et al., 2012). Due to the lack of information on the immunolocalization of cytoskeletal proteins in the normal camelid kidney, the current study investigated the distribution of vimentin, desmin, smooth muscle actin, and cytokeratin 19 in the kidney of the one-humped camel. It is envisaged that the information provided in this study on the normal camelid kidney could form a baseline for the diagnosis of pathological renal lesions in the camel.

MATERIAL AND METHODS

Animals and tissues sampling

Eight non-pregnant female adult camels, aged between 7 and 10 years and weighing 300 to 350 kg, were used in this study. Animals were slaughtered at Assalam abattoir, Khartoum, Sudan. The purpose of slaughtering animals was to provide meat intended for human consumption. A total of 120 tissue samples were selected from the right kidneys of the animals. The right kidney was taken because it was reached without much delay after the abdominal cavity being opened during slaughtering process. Fifteen samples were taken from each kidney (5 samples from the cortex, outer medulla, and inner medulla). All procedures in this study were approved by the College Research Board, College of Veterinary Medicine, University of Bahri, Khartoum, Sudan.

Histological and immunohistochemical staining

Tissue samples were fixed in 10% neutral buffered formalin for five days. Specimens were then processed for routine histological techniques and embedded in paraffin wax. For a general histological overview, sections of 5 µm thickness were stained with hematoxylin and eosin.

The immunostaining technique was performed on additional 5 µm thick sections using a Biogenex super sensitive one-step polymer-HRP detection system kit (Emergo Europe, The Hague, The Netherlands). Sections were deparaffinized and endogenous peroxidase activity was blocked, using 3% (v/v) hydrogen peroxide solution in water for 5 min. The slides were then rinsed in a 0.01 M phosphate buffered saline solution (PBS, pH 7.4) for 5 min. For antigen retrieval, the sections selected for desmin, smooth muscle actin and vimentin immunostaining were microwaved at 750 W for three cycles of 7 min each. After being allowed to cool for 20 min the sections were rinsed in PBS. The sections for cytokeratin 19 immunostaining were incubated with Proteinase K (Dakocytomation, Glostrup, Denmark) in 0.05 mol/L Tris-HCl (pH 7.6) solution for 3 min.

The sections were incubated at room temperature with anti-cytokeratin 19, desmin, smooth muscle actin or vimentin antisera. After incubation with primary antibodies the slides were rinsed in PBS and then incubated with the one-step polymer-HRP reagent (Emergo Europe, The Hague, Netherlands). Slides were then rinsed in PBS and antibodies were visualized by addition of a 3,3'-diaminobenzidine tetrachloride solution (Emergo Europe, The Hague, The Netherlands). The sections were counterstained with Mayer's haematoxylin. Table 1 shows the type, source, and dilution of the primary and secondary antibodies used in this study.

The immunostained, and haematoxylin and eosin-stained sections were viewed using a light microscope (Olympus BX63-Japan) connected to a digital camera (OlympusDP72). Images were then captured using the Cell Sens 510 software program.

Assessment of the immunostaining intensity

Three experienced examiners participated in the semiquantitative assessment of immunohistochemical reactivity independently. Previously, they agreed on the immunostaining intensities being qualified as strong (+++), moderate (++), weak (+) or negative (-).

For negative controls, the primary antibodies utilized in this study were replaced with mouse IgG1 (Dakocytomation, Glostrup, Denmark) which was diluted to the same concentration as the primary antibodies. Smooth muscle was used as a positive control for desmin and smooth muscle actin, while tonsillar tissue was used as a positive control for vimentin. Skin was used as a positive control for cytokeratin 19. No background staining was detected in the negative control sections. The variations in the immunostaining of sections used in this study were minor.

Table 1. Source and dilutions of primary antibodies used in the immunohistochemical technique.

Product name	Source and code	Type of antibody	Dilution	Incubation time
Monoclonal Mouse Anti-Vimentin	Dakocytomation, Glostrup, Denmark, code M7020	Monoclonal Primary Antibodies	1:200	1 hour
Monoclonal Mouse Anti-Human Smooth Muscle Actin	Dakocytomation, Glostrup, Denmark, code M0851	Monoclonal Primary Antibodies	1:50	1 hour
Monoclonal Mouse Anti-Human Desmin	Dakocytomation, Glostrup, Denmark, code M0760	Monoclonal Primary Antibodies	1:50	1 hour
Monoclonal Mouse Anti-Human Cytokeratin 19	Dakocytomation, Glostrup, Denmark, code GA615	Monoclonal Primary Antibodies	1:50	1 hour
One-step polymer-HRP reagent	Emergo Europe, The Hague, The Netherlands, code HK59506K	Anti-mouse and anti-rabbit secondary antibodies labeled with enzyme polymer	Ready to use	15 minutes

RESULTS

General histological overview of the camel kidney

The kidney was covered by a thick fibrous capsule which was composed of inner and outer layers (Fig. 1A). The inner layer contained numerous smooth muscle cells, while the outer layer was predominately composed of dense irregular connective tissue (Fig. 1A). The kidney parenchyma was divided into an outer cortex and an inner medulla (Fig. 1A, B). Cortical and juxtamedullary nephrons were observed in the kidney. The renal corpuscles of cortical nephrons were located in the outer region of the cortex, while the corpuscles of juxtamedullary nephrons were situated in the inner cortical region. The loops of Henle in cortical nephrons were short in contrast to the long loops of juxtamedullary nephrons, which extended into the medulla. The cortical region of the kidney contained renal corpuscles, proximal and distal convoluted tubules, as well as blood vessels (Fig. 1C, D). The renal corpuscles were composed of a glomerulus and glomerular capsule (Bowman's capsule). The glomerulus was formed by glomerular capillaries and mesangial cells (Fig. 1C). The glomerular capsule was formed by an inner visceral and an outer parietal layer. The visceral layer was composed of podocytes, which contained large, irregular-shaped nuclei, while a simple squamous epithelium formed the parietal layer (Fig. 1C).

The medulla of the kidney was subdivided into outer and inner regions, both of which contained collecting ducts. The outer region of the medulla

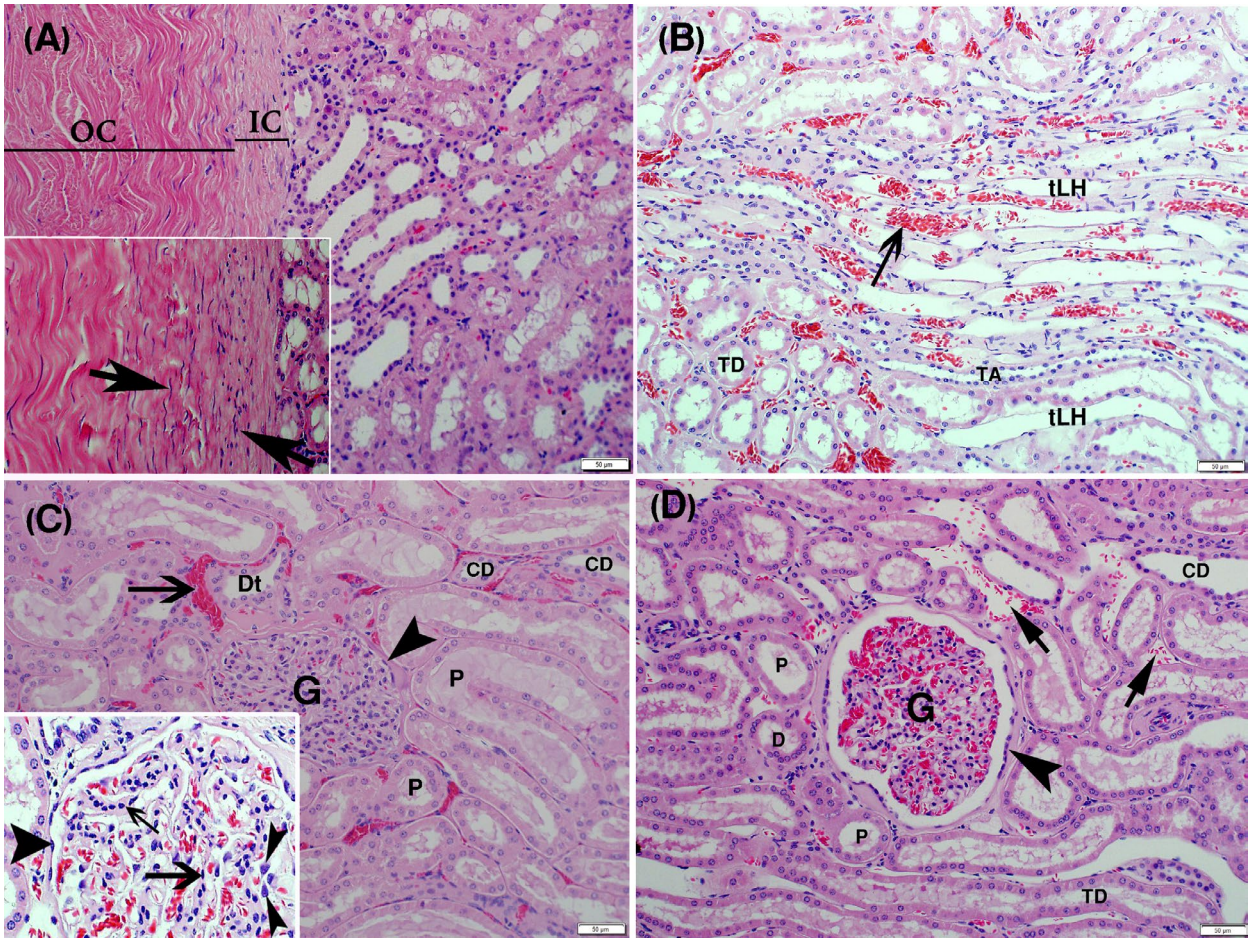

Fig. 1.- Photomicrographs of the cortex (A, C, D) and medulla (B) of the camel kidney. H&E staining. **(A)** Renal capsule and cortex. OC: Outer region of the renal capsule. IC: Inner region of the renal capsule. Inset: high magnification of inner region of the renal capsule containing smooth muscle cells (Arrows). **(B)** Outer region of the medulla. Limbs of the loop of Henle. TA: Thick ascending limb. TD: Thick descending limb. tLH: Thin limbs. Arrow: Vasa recta. **(C)** Renal cortex. G: Glomerulus. Arrowhead: Parietal layer of glomerular capsule. P: Proximal convoluted tubules. Dt: Distal convoluted tubule. CD: Collection ducts. Inset: Renal corpuscle. Small arrowheads: Podocytes. Small arrow: Intraglomerular mesangial cell. Large arrow: Endothelium of the glomerulus. Large arrowhead: Parietal layer of glomerular capsule. **(D)** Renal cortex. G: Glomerulus of a juxtamedullary nephron. Arrowhead: Parietal layer of a glomerular capsule. TD: Thick descending limb of the loop of Henle. CD: Collecting duct. P: Proximal convoluted tubules. Arrows: Blood vessels. Scale bars: 50 µm for A, B, C, D.

additionally contained the thick descending and ascending, as well as the thin limbs of the loop of Henle (Fig. 1B). In contrast, the thin limbs of the loops of Henle were the only tubular nephron components observed in the inner medulla.

Immunohistochemistry

The immunoreactivity of intermediate filaments in various regions of the camel kidney is shown in Table 2.

Vimentin

Strong vimentin immunostaining was demonstrated in podocytes which formed the visceral layer of the glomerular capsule (Fig. 2 A, B). Immunoreactivity was strong to moderate in cells forming the parietal layer of the glomerular capsule. However, interspersed between the vimentin immunoreactive cells were non-reactive cells (Fig. 2B). The thin limbs of the loops of Henle in cortical nephrons displayed strong vimentin immunoreactivity (Fig. 2C), whereas those of the juxtamedullary nephrons were non-reactive to vimentin (Fig. 2C, D and E).

Endothelial cells of renal blood vessels were predominantly immunoreactive to vimentin. In the cortex, these immunoreactive endothelial cells appeared to be mainly confined to cortical arteries and glomerular arterioles (Fig. 2A). In the medulla, strong immunoreactivity for vimentin was observed in the endothelial cells of the vasa rectae (Fig. 2C, D and E). However, in the medulla a few vasa rectae were lined by endothelia that non-reactive to vimentin (Fig. 2E).

Stromal cells in the interstitial tissue of the medulla and subepithelial connective tissue of the renal papilla exhibited strong immunoreactivity for vimentin (Fig. 2F). In addition, moderate to weak vimentin immunostaining was observed in fibroblasts located in the renal capsule, as well as in the trabeculae between nephrons.

No vimentin immunoreactivity was observed in the intraglomerular mesangial cells, epithelium of proximal and distal tubules (Fig. 2B), and collecting ducts (Fig. 2E, F).

Smooth muscle actin and desmin

Strong smooth muscle actin immunoreactivity was detected in intraglomerular mesangial cells (Fig. 3A, B). Strong smooth muscle actin immunoreactivity was also noted in the parietal cells of the glomerular capsules. However, some of the parietal cells were non-reactive to smooth muscle actin (Fig. 3B). Intense smooth muscle actin immunostaining was evident in smooth muscle cells forming the inner layer of the renal capsule (Fig. 3C). Additionally, strong smooth muscle actin immunostaining was demonstrated in the tunica media and tunica externa of muscular arteries (Fig. 3A, D), as well as in pericytes enclosing intertubular capillaries (Fig. 3C, D). In the medulla strong smooth muscle actin immunoreactivity was observed in the tunica media of vasa rectae (Fig. 3E, F).

Table 2. The intensity of the immunostaining of vimentin, smooth muscle actin, desmin, and cytokeratin 19 in the kidney of the camel.

Structures	Vimentin	SMA	Desmin	Cytokeratin 19
Podocytes	+++	-	-	-
Parietal cells of the glomerular capsule	-/++/+++	-/+++	-	-
Intraglomerular mesangial cells	-	+++	+	-
Cells of the thin limb of the loop of Henle*	+++	-	-	-
Endothelial cells	-/+++	-	-	-
Vascular smooth muscle cells	-	+++	+	-
Fibroblasts in the renal capsule	+	-	-	-
Smooth muscle fibres in the renal capsule	-	+++	-	-
Stromal cells below epithelium of renal papilla	+++	+++	-	-
Stromal cells in connective tissue trabeculae	+/++	+++	-	-
Fibroblasts in the interstitial tissue of medulla	+++	-	-	-

***** The loop of Henle of the outer cortical nephron

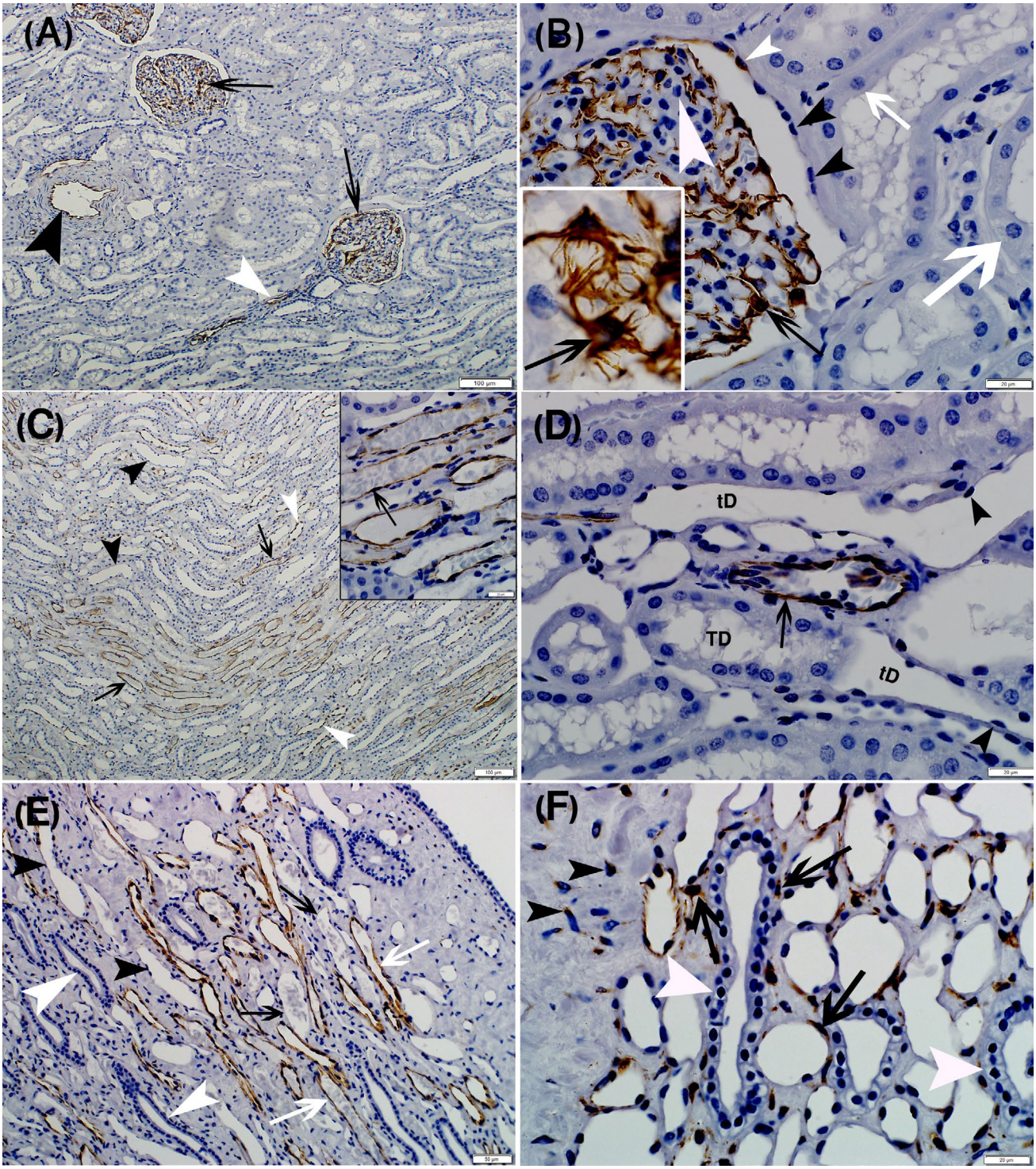

Fig. 2.- Photomicrographs of vimentin immunostaining in the cortex (A and B) and medulla (C, D, E and F) of the camel kidney. **(A)** Arrows: Strong vimentin immunopositive podocytes. Black arrowhead: Immunopositive endothelial cell of a small artery. White arrowhead: Immunopositive endothelial cell of a glomerular arteriole. **(B)** Black arrow: Strong vimentin immunostaining in a podocyte. Small white arrowhead: Strong vimentin immunostaining in a cell in the parietal layer of a glomerular capsule. Black arrowheads: Vimentin immunonegative cells in the parietal layer. Large white arrowhead: Vimentin immunonegative intraglomerular mesangial cell. Small white arrow: Vimentin immunonegative epithelium of a proximal convoluting tubule. Large white arrow: Vimentin immunonegative epithelium of a distal convoluting tubule. Inset: High magnification of a glomerulus and glomerular capsule. Arrow: Vimentin immunopositive podocyte. **(C)** White arrowheads: Vimentin immunopositive cells forming the thin limbs of the loop of Henle in superficial nephrons. Arrows: Immunopositive endothelial cells of vasa rectae in the outer medulla. Black arrowheads: Immunonegative cells of thin limbs of the loops of Henle in juxtamedullary nephrons. Inset: Arrow: Immunopositive endothelium of a vasa recta. **(D)** Arrowheads: Vimentin immunonegative cells lining the thin descending limbs (tD) of loops of Henle in juxtamedullary nephrons. Arrow: Immunopositive endothelium of a vasa recta at the junction between outer and inner regions of the medulla. TD: Thick descending limb of a loop of Henle. **(E)** White arrows: Immunopositive endothelial cells of vasa rectae in the inner medulla. Black arrows: Immunonegative endothelial cells. Black arrowheads: Immunonegative cells of thin limbs of the loops of Henle of juxtamedullary nephrons. White arrowheads: Immunonegative cells of collecting ducts. **(F)** Arrows: Immunopositive stromal cells in the interstitial tissue of the medulla. Black arrowheads: Immunopositive stromal cells in the subepithelial connective tissue of a renal papilla. White arrowheads: Immunonegative cells of collecting ducts. Scale bars: 100 µm for A, C; 20 µm for B, D, F; 50 µm for E.

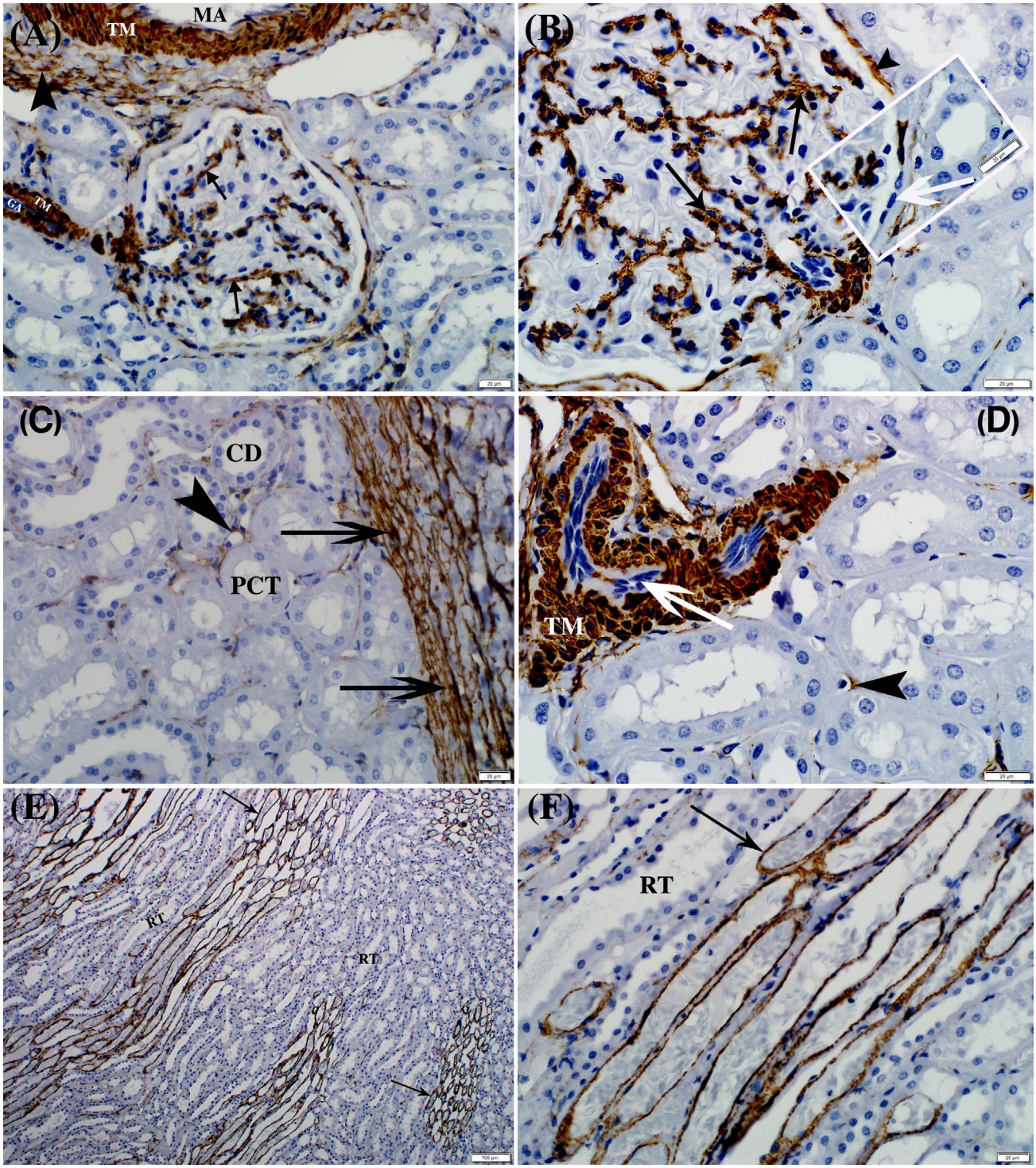

Fig. 3.- Photomicrographs of smooth muscle actin immunostaining in the cortex (A and B) and medulla (C, D, E and F) of the camel kidney. **(A)** Smooth muscle actin immunoexpression in intraglomerular mesangial cells (arrows), as well as in the tunica media (TM) of a muscular artery (MA) and glomerular arteriole (GA). Smooth muscle actin immunoexpression is also present in smooth muscle cells in the tunica externa (arrowhead) of the muscular artery. **(B)** Smooth muscle actin immunostaining in the cytoplasm of intraglomerular mesangial cells (arrows), as well as in the parietal cell layer (arrowhead) of the glomerular capsule. Inset: Arrow: Vimentin immunonegative cell in the parietal layer of a glomerular capsule. **(C)** Smooth muscle actin immunoreactivity in smooth muscle cells of the renal capsule (arrows), as well as in a pericyte of a capillary (arrowhead) interposed between a proximal convoluted tubule (PCT) and a cortical collecting duct (CD). **(D)** Strong smooth actin immunostaining in the tunica media (TM) of a muscular artery, as well as in a pericyte of an intertubular capillary (arrowhead). Arrow: Smooth muscle actin immunonegative endothelium. **(E) & (F)** Arrows: Strong smooth muscle actin immunoreactivity in smooth muscle cells of the tunica media of the vasa rectae. RT: Renal tubules. Scale bars: 20 µm for A, B, C, D, F; 100 µm for E.

Desmin immunostaining was restricted to intraglomerular mesangial and vascular smooth muscle cells (Fig. 4A, B). The proximal and distal convoluted tubules, as well as the collecting ducts were reactive to vimentin, smooth muscle actin, desmin, and cytokeratin 19.

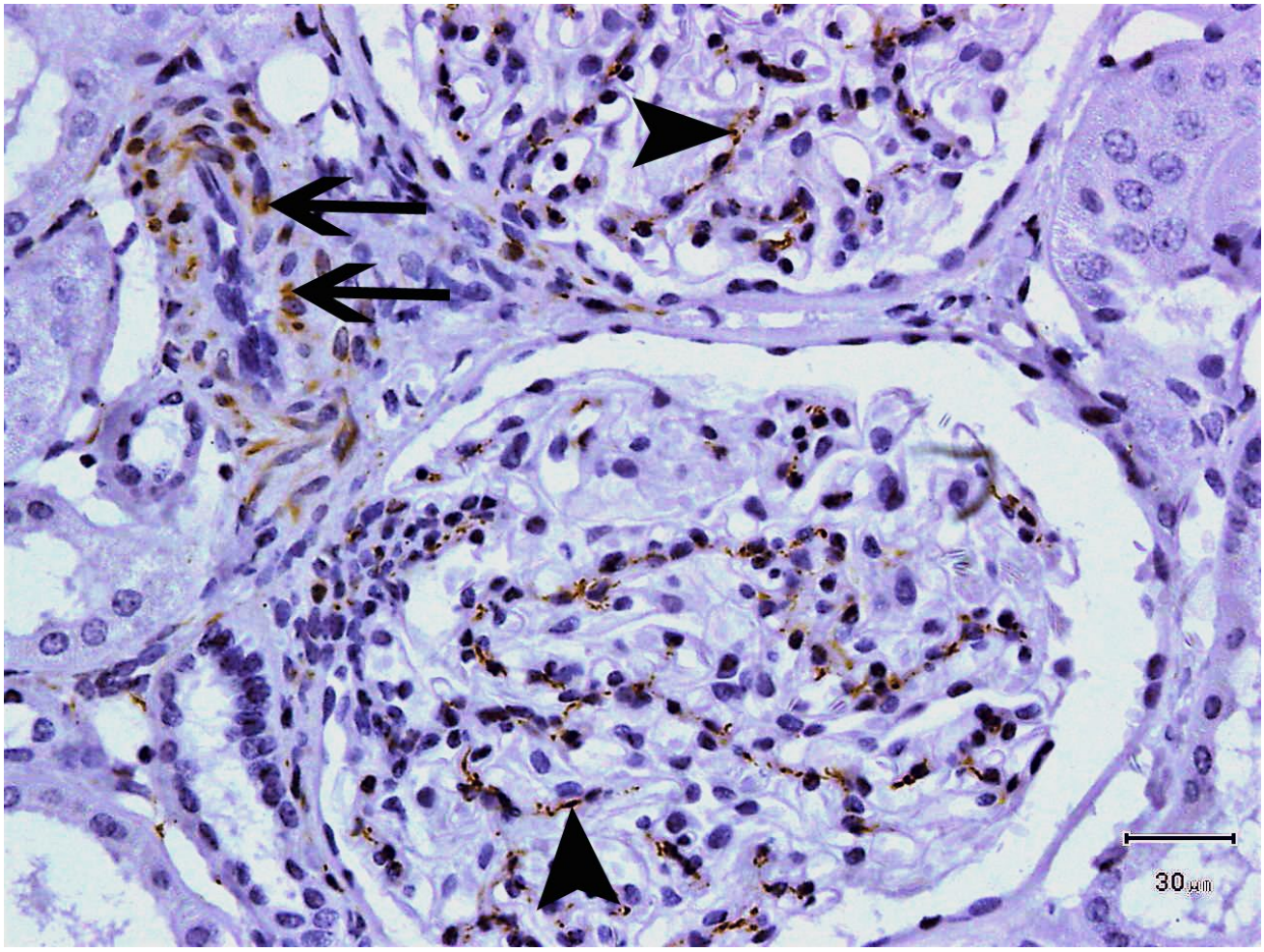

Fig. 4.- Photomicrograph of desmin immunostaining in the cortex of camel kidney. Immunopositive intraglomerular mesangial cells (arrowheads). Immunopositive smooth muscle cells of a glomerular arteriole (arrows). Scale bar: 30 µm.

Cytokeratin 19

No immunoreactivity for cytokeratin 19 was detected in the camel kidney.

DISCUSSION

Renal capsule

The renal capsule is known to play a role in the establishment of an effective renal interstitial pressure (Khraibi and Knox, 1989), and subsequently water excretion (Farrugia et al.,1992). The presence of smooth muscle cells in the inner capsular layer of camel kidney has previously been reported by Eissa et al. (2018), and confirmed in the current study. The present study has shown that the smooth muscle cells are immunoreactive for smooth muscle actin, but non-reactive to desmin. The occurrence of smooth muscle cells in the renal capsule has been reported in several mammalian species and is known to be involved in the contractile ability of the capsule (Kobayashi, 1978). In addition, the thick collagenous layer of the renal capsule functions to protect the kidney from traumatic injuries (Orchard et al., 2014). Thus, as shown in the current study, the main component of the outer region of the renal capsule dense irregular connective tissue with associated vimentin immunoreactive fibroblasts. Fibroblasts have been considered as one of the major components of renal capsule in several mammals, such as mouse, rat, guinea pig and rabbit (Kobayashi, 1978). In addition, fibroblast in the kidney were demonstrated by the immunolocalization of vimentin (Boor and Floege, 2012).

Renal parenchyma

The general histomorphological findings of the present study were similar to those reported in

previous investigations on the camel (Abdalla and Abdalla, 1979; Beniwal et al., 1998; Wenhui and Huaitao, 2000; Xu et al., 2009). Furthermore, the present study confirmed that the renal histology of the camel does not differ significantly from other mammalian species, such as the dog (Bulger et al., 1979), cattle (Mbassa, 1988), and sheep (Singh et al., 2018).

In this study, vimentin was immunolocalized in podocytes, vascular endothelial cells, and medullary interstitial fibroblasts. These findings are plausible as it is known that vimentin occurs in cells of mesenchymal origin (Leong et al., 2003; Satelli and Li, 2011). In addition, these results are in agreement with studies carried out on several mammals, including the human (Essawy et al., 1997), domestic ruminants (Maretta and Marettová, 1999; Yaoita et al., 1999), rodents (Zou et al., 2006; Yaoita et al., 1999; Sistani et al., 2013) dog (Yaoita et al., 1999), and polar fox (Laszczyńska et al., 2012). Intraglomerular mesangial cells, and the epithelia of proximal and distal tubules in the current study did not react with vimentin. These reports are contrary to observations made in the human and polar fox in which vimentin immunoreactivity was demonstrated in the epithelia of the proximal and distal tubules (Laszczyńska et al., 2012; Smeets et al., 2013). Furthermore, intraglomerular mesangial cells in humans, rats, ruminants, and polar foxes have been reported to be immunoreactive for vimentin (Stamenkovic et al., 1986; Oosterwijk et al., 1990; Scanziani et al., 1993; Essawy et al., 1997; Maretta and Marettová, 1999; Yaoita et al., 1999; Zou et al., 2006; Laszczyńska et al., 2012; Smeets et al., 2013). These results indicate that species variations exist in the immunolocalization of vimentin in the mammalian kidney. However, the functional significance of these interspecies variations is unknown.

In the current study smooth muscle actin immunoreactivity was detected in the tunica media of blood vessels throughout the renal tissue. This is similar to findings reported in the rat (Carey et al., 1992) and human (Essawy et al., 1997; Novakovic et al., 2012). Smooth muscle actin has also been demonstrated in myofibroblasts located in the interstitium of normal human kidney (Essawy et al., 1997; Gonlusen et al., 2001). In the present study no myofibroblasts appeared to be present.

The current findings revealed that smooth muscle actin immunostaining was demonstrated in the parietal layer of the glomerular capsule. This may suggest a contractile function of the parietal cells of camel kidney. Interestingly, the present study showed that some of the parietal cells of the glomerular capsule were non-reactive when stained either with vimentin or smooth muscle actin. It is plausible that the negative parietal cells for vimentin might display positive reactivity for smooth muscle actin, and the reverse is true. However, further double immunostaining studies will need to be conducted to confirm this assertion.

In this study, positive immunostaining for smooth muscle actin was observed in intraglomerular mesangial cells. This is in agreement with the findings of studies conducted on the human kidney (Schlöndorff and Banas, 2009; Young et al., 2014). It is known that intraglomerular mesangial cells contain the intermediate filaments actin and myosin (Davies, 1994; Stockand and Sansom, 1998). Consequently, intraglomerular mesangial cells are thought to have a contractile ability, which is utilized in the control of glomerular blood flow (Reece, 2015).

It is noteworthy that the immunostaining of desmin in this study was weaker than that of smooth muscle actin. One possible explanation for this difference could be that the fixation of renal tissue with formalin may significantly enhance the immunostaining sensitivity to smooth muscle actin rather than desmin (Rangdaeng and Truong, 1991). Desmin immunostaining in the present study was observed primarily in intraglomerular mesangial cells, as well as in vascular smooth muscle cells. Similar findings were reported in the human (Oosterwijk et al., 1990), rat (Zou et al., 2006) and polar fox (Laszczyńska et al., 2012). However, studies by Essawy et al. (1997), as well as Gonlusen et al. (2001) did not detect desmin immunoreactivity in the human kidney.

It is known that there are approximately twenty different types of cytokeratins, with at least two

occurring in most epithelial cells (Leong et al., 2003). In the human kidney, cytokeratin 19 has been demonstrated in the parietal layer of the glomerular capsule (Stamenkovic et al., 1986), as well as in the loop of Henle (Achtstätter et al., 1985), distal convoluted tubules (Oosterwijk et al., 1990) and collecting ducts (Şen et al., 2010). However, the current study did not detect cytokeratin 19 in the camel kidney. It has been reported that filaments generated from different types of cytokeratins have distinct physical properties, suggesting tailor-made networks of intermediate filaments suitable for tissue structural requirements of tensile strength, flexibility, and dynamics (Fuchs et al., 1994). Therefore, it is most likely that the epithelial cells of the camel kidney may have types of cytokeratins other than cytokeratin 19.

In conclusion, the results of the present study have shown that similarities and differences exist in the immunolocalization of cytoskeletal proteins in the camel when compared to other mammals. The presence of smooth muscle actin immunoreactivity in the parietal cell layer of the glomerular capsule suggests a contractile function of the parietal cells in the camel kidney. Significantly, the results of the study suggest that vimentin and smooth muscle actin can be used as markers for the identification of podocytes and intraglomerular mesangial cells, respectively, in the camel kidney.

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