Comparative Studies on the Renal Structural Aspects of the Mammalian Species Inhabiting Different Habitats

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Abstract: The current investigation was carried out to reveal the structural aspects of the kidney of the herbivorous guinea pigs, Cavia porcellus, inhabiting mesic environment, the insectivorous hedgehogs, Paraechinus aethiopicus, inhabiting arid environment and the omnivorous spiny mice, Acomys russatus, inhabiting arid environment in an attempt to elucidate whether variations in the nature of habitat and /or diet may associated with special structural renal adaptations. The kidneys of the selected species were studied morphologically, histologically and ultrastructurally. The results were markedly varied, with the spiny mice having the lightest body weight, the heaviest relative kidney weight, the well-developed complex renal pelvis, the fewest nephron numbers, the least total glomerular volume (TGV), numerous giant vascular bundles, the fewest and the narrowest filtration slits, the thickest basal lamina of both glomerular capillaries and epithelial lining of proximal and distal tubules, well developed elaborated basal infoldings and the greatest number of elongated mitochondria compared to those of the guinea pigs and the hedgehogs respectively. In contrast, the hedgehogs showed some peculiar structural features, including the huge nephron number and the greatest total glomerular volume.

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1. Introduction:

Adaptations of different mammalian species to life in various habitats may include different combinations of cellular, physiological, behavioral, and ecological characteristics (Gallardo *et al*., 2005; El-Gohary *et al*., 2008 and El-Gohary, 2009). The different mammalian species from arid and semiarid habitats are faced with the problem of water conservation in conditions where the spatial and temporal availability of free water is limited or scarce. Classically, at the individual level of biological organization, desert dwelling rodents display many physiological features that favor body water-sparing mechanisms include a high level of constitutive colonic water absorption, related to AQP-1 expression in apical and basolateral membranes of distal colonic epithelial cells (Gallardo *et al*., 2002); reduced water evaporation through nasal passages (Corte´s *et al.*,2000); and high urine concentration (Jackson *et al*., 2003 and El-Gohary, 2009).

The physiological adaptation of small rodents to arid conditions is achieved mainly through concentrating ability of their kidneys (El-Gohary, 2009). Conservation of water by the kidney is of crucial importance for the kangaroo rat, which does not drink and can obtain water only from catabolism, while, other desert rodents obtain water from their diet (Bozinovic *et al*., 2003).

Several renal a adaptations that may be critical in the improvement of water conservation are described (Cooper & Withers, 2010). These adaptations include variations in the relative medullary thickness (Tirado *et al*., 2008; Coleman & Downs, 2009 and Cooper & Withers, 2010), the length of the renal papilla (El- Gohary, 2009), number of nephrons (El-Gohary *et al*., 2008 and El-Gohary, 2009), percentage of long-looped nephrons (Altschuler *et al.*, 1979), nephron heterogeneity (Altschuler *et al*., 1979), development of pelvic fornices (El-Gohary *et al*., 2008 and El-Gohary, 2009), confluence of collecting ducts, vascular bundles in the inner stripe of the outer medulla (Pannabecker *et al*., 2008 and Yuan & Pannabecker, 2010), thin descending limb epithelium, and relative development of the three medullary zones (Pannabecker *et al*., 2008 and Yuan & Pannabecker, 2010).

The present study was designed to elucidate whether variations in the nature of habitat and /or diet of the selected mammalian species may associated with special adaptive renal structures.

2. Materials and Methods

1- Experimental Animals

The experimental animals of the present work included three different mammalian species of different orders which inhabiting vastly different habitats and feed on different diet. The investigated animals included guinea pigs (*Cavia porcellus*), Ethiopian hedgehogs (*Paraechinus aethiopicus*) and Golden spiny mouse (*Acomys russatus*). Guinea pigs inhabiting mesic areas and are exclusively herbivore. Hedgehogs, on the other side, are insectivorous desert inhabiting animals. They feed exclusively on insects. Golden spiny mice live in arid and semi-arid environments like deserts (South Sinai especially Saint Catherine mountain). They are omnivorous animals, where the high-salinity vegetation and invertebrates are often the only available source of nutrients and water (Kronfeld-Schor &Dayan, 1999). Ethiopian hedgehogs and Golden spiny mice were collected from their natural habitat. Guinea pigs, on the other hand were purchased from the local market.

All the studied animals were adult and healthy. Nine adult males of each studied species were weighed, sacrificed with sharp razor blade. The sacrificed animals were promptly dissected to remove out the kidneys for subsequent measurements. For the purpose of this study, the anatomy of both kidneys was assumed to be identical. Therefore, the right kidneys of the studied species were processed routinely for light microscopy and transmission electron microscopy, while, the left kidneys were used for nephron enumeration.

2- Morphometric Studies

The right and left kidneys were weighed separately and the papillary length of the kidneys were measured using a binocular dissecting microscope fitted with a calibrated ocular micrometer. The thickness of the cortical and medullary regions was taken from a median cross section parallel to the flattened surface of the kidney. The relative medullary thickness (RMT) was calculated following the method of El-Beltagy (2002).

3-Nephron Enumeration

In the present work the number of nephrons were enumerated following the method described by Maluf (1991).

4- Estimation of Glomerular Size

Histological renal sections of the studied species were used to evaluate glomerular size. Ten glomeruli from each nephron populations [superficial (SF), mid-cortical (MC) and juxta-medulary (JM)] were measured under light microscope fitted with ocular micrometer eye piece at magnification power of 100 X. (Solomon,1974).

The JM/S ratio for glomerular size was considered as an index of inter-nephron heterogeneity of each species.

5- Histological Studies

The right kidneys of the studied species were cut along the mid dorsal plane and immediately fixed in 10% neutral formaline. The tissue was washed in tap water. Then dehydrated in ascending grades of ethyl alcohols, cleaned in xylene and finally embedded in paraffin wax at 60˚C. The paraffin sections at 5-6µm in thick were prepared and stained with Haematoxylin and Eosin according to Carleton (1980).

6- Ultrastructural Studies

Kidneys were removed immediately and small pieces ($1mm^3$) of the cortical tissue of the right kidneys of the studied species were excised and immersed in 2.5% glutaraldehyde in 0.1 M sodium cacodylate buffer at pH 7.2, then the tissue samples were post-fixed in 1% buffered osmium tetroxide, after which the samples were dehydrated in ascending series of ethyl alcohol, cleared in propylene oxide and embedded in epon (Casotti *et al*., 1998). The present ultrastructure studies were done in the electron microscope unit of Faculty of Science, University of Ain Shams, Cairo.

7- Statistical Analysis

The present data were analyzed by a one-way ANOVA (Lindman, 1974), whereas, P values <0.05 were accepted for minimal statistical significance. Results were reported as mean ± SE.

3. Results

1- Body and Kidney Weights

As shown in Table (1), the mean body weight of the guinea pigs is significantly (P<0.001) heavier than the body weights of both the hedgehogs and the spiny mice respectively. Also, the mean body weight of the hedgehogs is significantly (P<0.001) heavier comparing to that of the spiny mice.

As shown in Table (1), the guinea pigs have significantly (P<0.01) (P<0.001) heavier right and left kidneys than those of the hedgehogs respectively, followed by the spiny mice which have the lightest absolute kidney weights. In contrast to the absolute kidney weights, the relative kidney weights to body weights show an opposite pattern.

2- The Corticomedullary Thickness and Renal Papilla

The cortical thickness of the guinea pig right and left kidneys are significantly (P<0.05) and

(P<0.001) thicker comparing to those of the hedgehogs and spiny mice respectively.

In addition, the absolute medullary thickness of the right and left kidneys of the guinea pigs are obviously thinner comparing to those of the right and left kidneys of the hedgehogs. However, the medullary thickness of the hedgehogs is markedly thicker comparing to those of the right and left kidneys of the spiny mice (see Table 1).

The relative medullary thickness of the investigated species followed an opposite pattern when compared to the absolute medullary thickness as cited in Table (1).

3- Number of Nephrons

As shown in Table (2), the guinea pig has approximately half the number of nephrons compared to the hedgehogs and twice that of the spiny mice. In addition, the number of nephrons per gram kidney weights of the investigated species followed the same pattern of the absolute number of nephrons. Moreover, the relative number per gram body weight is significantly (P<0.001) lower for the spiny mice compared to those for the guinea pigs and the hedgehogs respectively.

4- Glomerular Size and the Total Glomerular Volumes

As shown in Table (2), the juxta-medullary nephrons have the biggest size followed by the mid-cortical nephrons and then the superficial ones which have the smallest size for all the studied species. Concerning the size of the glomeruli of the guinea pigs, they are larger (except the juxtamedullary ones of the hedgehogs only) than the corresponding superficial, midcortical and juxtamedullary nephrons of the hedgehogs and the spiny mice respectively. In addition, the size of the glomeruli of the hedgehogs is distinctly larger than the respective data of the spiny mice for all the different types of nephron populations. Regarding the values of the JM/S ratio for glomerular size of the guinea pigs is lower than those of the hedgehogs and spiny mice respectively. However, the differences are insignificant.

The values of the total volume of the glomeruli are significantly (P<0.01) lower than the corresponding values in the hedgehogs and significantly higher (P<0.001) than that of the spiny mice which have the lowest values among the studied species.

5- Renal Gross Anatomy

As shown in Figure (1); the kidney of the guinea pigs seems to be the largest one when compared to the kidneys of the hedgehogs and the spiny mice which have the smallest one among the studied species. The guinea pigs have extremely short blunt renal papilla while that of the hedgehogs is moderately long and broad. The spiny mice, on the other side, have well-developed long sharp pointed renal papilla extending into the ureter.

6- Histological Studies

As shown in Figure (2); both the guinea pig and the hedgehog kidneys show relatively high density of large renal corpuscles evenly distributed throughout the cortex. On the other side, the spiny mice kidney shows distinctly less density of relatively small renal corpuscles. Each renal corpuscles consists of a Bowman`capsule and a glomerulus (Fig.3). The degree of the granulation of the macula densa of the different studied species is varied, with the spiny mice having the highest degree followed by the hedgehog then the guinea pigs which show the lowest degree of granulation (Fig.4).

The most outstanding components of the inner stripe of the outer medulla are the presence of the vascular bundles, each of which are formed of arterial and venous vasa recta and thin descending limbs of loop of Henle. The type of the medullae of the studied species are varied, with the guinea pigs showing simple type and the hedgehogs show moderately complex type, while the spiny mice have the most complex type of medulla among different investigated species. In addition, the vascular bundles are either of the simple type as in the guinea pigs or the giant type as in both the hedgehogs and the spiny mice. However, the density of the vascular bundles of the spiny mice is obviously greater than those of the hedgehogs (Fig.5).

The inner medulla and papilla contain only collecting ducts, thin limbs and capillary structures. The guinea pigs have extremely short blunt renal papilla. While the hedgehogs and the spiny mice have moderately long and well-developed long sharp pointed renal papillae respectively (Fig.6).

The renal pelvis appeared as a dilated cavity of the proximal end of the ureter, lodged in the sinus and facing the renal papilla. It is formed of either a simple pelvis as in the guinea pigs or a relatively complex as in the hedgehogs or a complex type with well- developed secondary fornices (pelvic recesses) and highly developed evaginations that extended between cortical and medullary tissues as in the spiny mice (Fig.6). Each fornix is formed of two folds or leaf-like projections which are lined with simple squamous to simple cuboidal epithelium with minimum amount of connective tissue.

7- Ultrastructural Studies

The capillary loops of the guinea pigs are narrower with thinner basal lamina than those of the hedgehogs. While, the lumen of the capillary loops of the spiny mice are obviously wider with markedly thick basal lamina comparing to the respective structures of both the guinea pigs and the hedgehogs (Fig.7). The number, the size of the filtration slits as well as the thickness of the glomerular basal lamina are markedly varied among the studied species, with the guinea pigs have more and wider filtration slits and thinner basal lamina comparing to those of the hedgehogs and the spiny mice which show the fewest and narrowest filtration slits and the thickest basal lamina. The thickness of the filtration barrier of the guinea pigs is obviously thin when compared to that of the hedgehogs. On the other side, the spiny mice have the thickest filteration barrier.

As shown in Figure (8); the length and the abundance of the microvilli of the apical border of the epithelial lining of the proximal tubule are obviously varied, with the guinea pigs having relatively short and less abundance microvilli comparing to those of the hedgehogs and the spiny mice whereas the latter have the longest and the most abundance microvilli among the investigated species.

The guinea pigs have relatively numerous numbers of rounded mitochondria in comparison with those of the hedgehogs. However, the spiny mice show huge numbers of elongated mitochondria with distinct densely packed cristae which occupy more area of the renal tubular epithelium. The basal lamina of the guinea pigs is distinctly thin compared to those of the hedgehogs which have moderately thick basal lamina and spiny mice which have the thickest basal lamina among the studied species.

As shown in Figure (9); the abundance of the mitochondria and the degree of the development of the basal infoldings as well as the thickness of the basal lamina of the distal tubule are varied; with the spiny mice having numerous mitochondria and thicker basal lamina and well-developed basal infoldings compared with either the guinea pigs or the hedgehogs.

Table (1): Body weights (BW), absolute kidney weights (AKW), relative kidney weights (RKW), Corticomedullary thickness; cortex (C), absolute medullary thickness (AMT), relative medullary thickness (RMT) and length of renal papillae (RP) of guinea pigs (*Cavia porcellus*), Ethiopian hedgehogs *(Paraechinus aethiopicus)* and Golden spiny mice (*Acomys russatus*).. All the data are represented as means ± standard errors. Numbers in parentheses are the numbers of the experimental animals.

Experimental Animals	**BW (g)**	**Kidney weight (g)**				**Corticomedullary thickness**						**RP (cm)**	
		AKW		**RKW**		**C (cm)**		**AMT (cm)**		**RMT**			
		R	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
1- Guinea pigs (*Cavia porcellus*) (9)	380 ± 24.3	1.3± 0.08	1.3± 0.08	0.03± 0.001	0.03± 0.001	0.4 ± 0.03	0.4 ± 0.04	0.5± 0.03	0.5± 0.02	2 ± 0.4	2.1 ± 0.2	0.5± 0.02	0.4± 0.01
2- Hedgehogs (*Paraechinus aethiopicus*) (9)	186.1± 9.9	1± 0.04	1± 0.04	0.05± 0.003	0.05± 0.002	0.3± 0.02	0.3 ± 0.02	0.7 ± 0.06	0.7 ± 0.04	4 ± 0.6	3.8 ± 0.2	0.8 ± 0.06	0.7 ± 0.03
3- Spiny mice (*Acomys russatus*) (9)	22.7 ± 1.4	0.2± 0.01	0.1 ± 0.01	0.07± 0.006	0.05± 0.006	0.2 ± 0.01	0.2 ± 0.01	0.3 ± 0.02	0.3 ± 0.01	10.8± 1.2	8.1± 1.4	1 ± 0.03	0.9 ± 0.02
Probability (1) vs (2)	P < 0.001 (S)	P<0.01 (S)	P < 0.001 (S)	P<0.01 (S)	P < 0.05 (S)	P < 0.05 (S)	P> 0.05 (NS)	P<0.01 (S)	P < 0.001 (S)	P > 0.05 (NS)	P > 0.05 (NS)	P > 0.05 (NS)	P<0.01 (S)
(1) vs (3)	P < 0.001 (S)	P < 0.001 (S)	P < 0.001 (S)	P < 0.001 (S)	P<0.01 (S)	P < 0.001 (S)	P < 0.05 (S)	P<0.01 (S)	P < 0.001 (S)	P < 0.001 (S)	P < 0.001 (S)	P < 0.01 (S)	P < 0.05 (S)
(2) vs (3)	P < 0.001 (S)	P < 0.001 (S)	P < 0.001 (S)	P < 0.05 (S)	P > 0.05 (NS)	P < 0.05 (S)	P > 0.05 (NS)	P < 0.001 (S)	P < 0.001 (S)	P < 0.001 (S)	P<0.01 (S)	P < 0.001 (S)	P < 0.001 (S)

Table (2) : Number of nephrons per whole kidney (WK), per gram kidney weight (GKW) , per gram body weight (GBW) , glomerular volumes (mm^3) of superficial (S), mid-cortical (MC) , juxta-medullary (JM) nephrons as well as JM/S ratio of glomerular size and total glomerular volume (GV) (mm^3) of guinea pigs (*Cavia porcellus*), Ethiopian hedgehogs *(Paraechinus aethiopicus)* and Golden spiny mice (*Acomys russatus*). All the data are represented as means ± standard errors. Numbers in parentheses are the numbers of the experimental animals.

Experimental Animals	Number of nephrons			Size of different glomerular Populations (µm^3)				Total glomerular volume per gram body weight (GV) (mm^3)
	WK	GKW	GBW	S	MC	JM	JM/ S	
1-Guinea pigs (*Cavia porcellus*) (9)	29367± 3961.8	2232 3.6± 4904.8	74.2± 7.3	204± 42	391± 36.9	661± 79	3.24± 1.59	32.34± 4.2
2- Hedgehogs (*Paraechinus aethiopicus*)	43932.3± 2168.4	41331.7± 2472.8	238.2 ± 12	170.7± 29.3	386.2 ±81.9	737.7± 68.6	4.32± 1.43	101.87± 15.9
3- Spiny mice (*Acomys russatus*) (9)	1569± 235	15640± 305	58.9± 12	132.1± 16.4	171 ± 29.4	460.3 ±24.8	3.48± 1.54	17.58± 3.5
Probability (1) vs (2)	P<0.01 (S)	P<0.01 (S)	P <0.001 (S)	P > 0.05 (NS)	P > 0.05 (NS)	P > 0.05 (NS)	P > 0.05 (NS)	P < 0.01 (S)
(1) vs (3)	P < 0.001 (S)	P <0.001 (S)	P < 0.001 (S)	P > 0.05 (NS)	P < 0.05 (S)	P > 0.05 (NS)	P > 0.05 (NS)	P<0.001 (S)
(2) vs (3)	P < 0.001 (S)	P <0.001 (S)	P <0.001 (S)	P > 0.05 (NS)	P < 0.05 (S)	P < 0.05 (S)	P > 0.05 (NS)	P<0.001 (S)

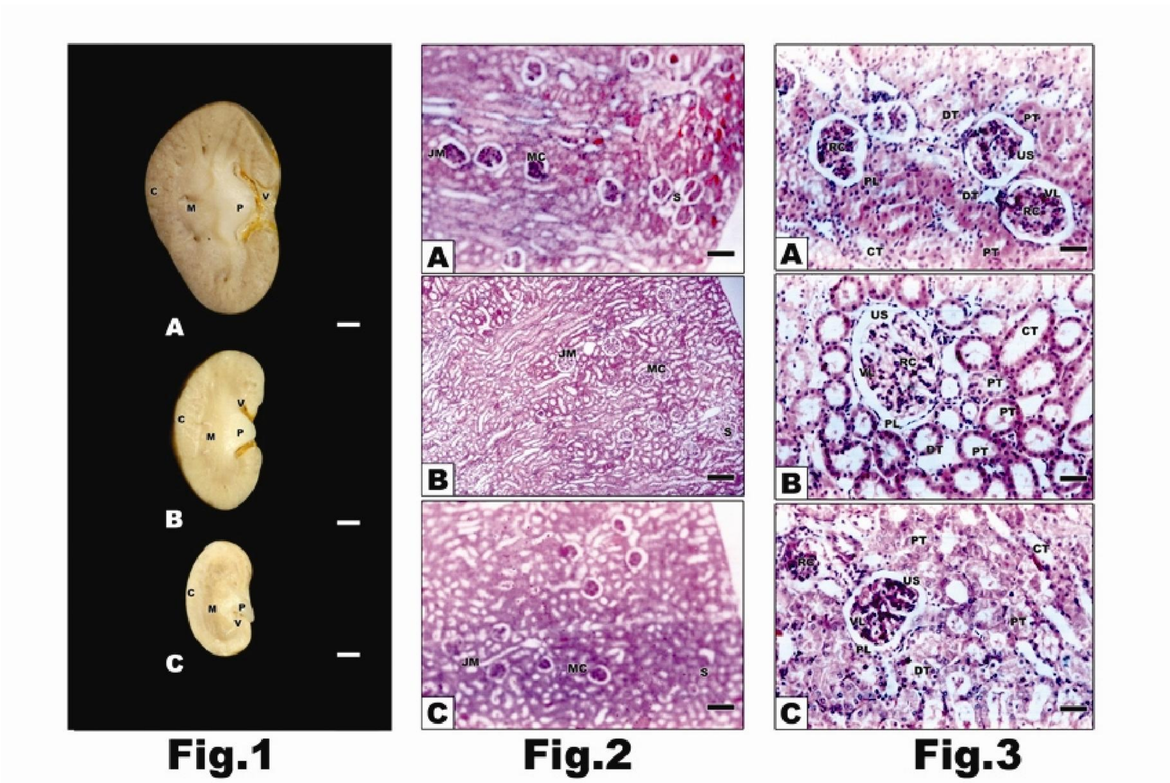

Fig.1: Photomicrograph of cross mid-sagittal sections of the kidney of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing cortex (C), medulla (M), renal papilla (P) and renal pelvis (V). X 10.

Fig.2: Photomicrograph of transverse sections of the kidney of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing the main nephron populations (S, MC and JM). H&E X100.

Fig.3: Photomicrograph of transverse sections through the cortical region of the kidney of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing renal corpuscles (RC) and tubules (PT, DT and CT). H&E X250.

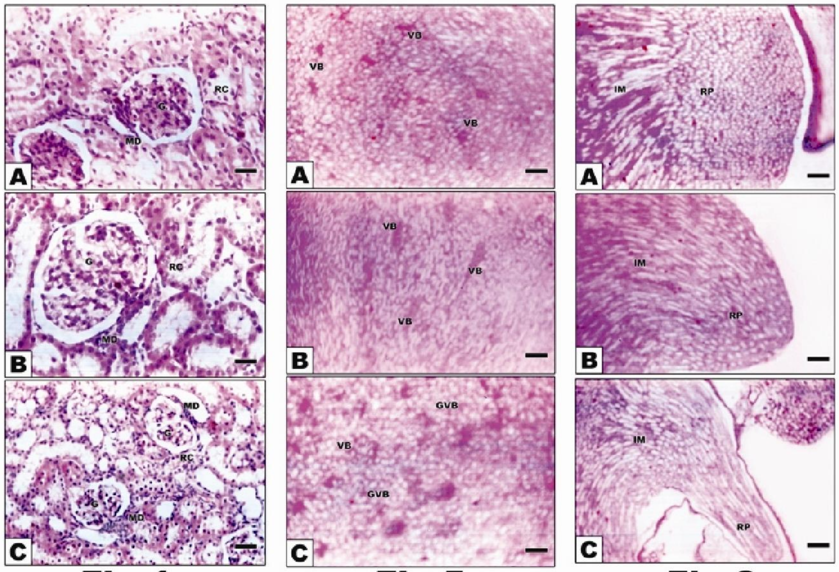

Fig.4 Fig.5 Fig.6

Fig.4: Photomicrograph of transverse sections through the cortical region of the kidney of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing macula densa (MD). H&E X 300.

Fig.5: Photomicrograph of transverse sections of the kidney of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing simple vascular bundles (VB) and giant type (GVB). H&E X 100.

Fig.6: Photomicrograph of transverse sections of the kidney of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing shapes of renal papillae (RP). H&E X40.

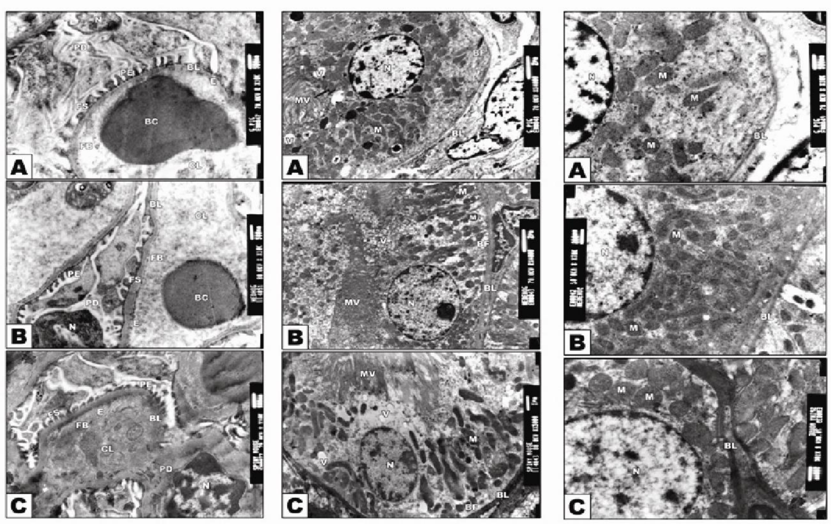

Fig.7 Fig.8 Fig.9

Fig.7: Electron micrograph of the renal corpuscle of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing capillary loops (CL), endothelium (E), pedicles (PE), basal lamina(BL), filtration slits (FS) and filtration barrier (FB). X10000.

Fig.8: Electron micrograph of the epithelial lining of the proximal tubule segment of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing microvilli (MV), mitochondria (M), vacuoles (V) and nucleus (N). X7500.

Fig.9: Electron micrograph of the epithelial lining of the distal tubule segment of the guinea pig (A), the hedgehog (B) and the spiny mouse (C) showing mitochondria (M) and basal lamina (BL). X7500.

4. Discussion:

It has been well established that water availability is limited, or scarce, in arid and semi-arid habitats. Thus the different animal species live in these environments are faced with the problem of water conservation. Thereby, the efficient water economy can be examined through the ability of the kidney to produce a concentrated urine (Weissenberg & Shkolnik ,1994).

Although there is a strong correlation between the structure of the mammalian kidney and urinary concentrating ability (Cooper & Withers, 2010). However, it appears difficult to build a coherent picture of the concentrating system of the mammalian kidney. This may be due to the diversity of the factors involved and to considerable interspecies differences.

In the present study, the body weights of the different examined species were distinctly varied; with the guinea pigs had the heaviest body weight followed by the hedgehogs then the spiny mice which had the lightest body weight. The present findings go parallel with the concept that small species have more powerfully-concentrating kidneys than do large species (Yang & Bankir, 2005). Another feature that deserves attention is the scaling of food intake/metabolic rate according to size (Smith, 1984). The smaller the size, the higher are these parameters and the higher the excretory needs in relation to body weight.

The absolute kidney weights of the selected animals followed the same pattern of the body weights; the guinea pigs showed the highest values followed by the hedgehogs then the spiny mice which had the lowest values. The relative kidney weights followed an opposite pattern; with the spiny mice had the highest value followed by the hedgehogs then the guinea pigs which had the lowest values. These observations may be related to the high water content of vegetables; the sole diet of the guinea pigs. So, these animals did not need to conserve water. In contrast, both the spiny mice and the hedgehogs might require larger relative renal tissue to satisfy their water needs from a less liquid diet. Further support of such findings comes from the concept that the smaller animals would need greater renal concentration powers to conserve water (Gordge and Roberts, 2008), since they have exposed surface areas proportionality greater to the total water content. Therefore, they could desiccate more rapidly.

The relative medullary thickness has been used as an index of an organism's ability to generate hypertonic urine and, thus, as an adaptation to xeric habitats. Consequently, it is expected that species with high RMT indices will be able to increase their urine concentration during spells of drought that lead to increase salinity of water sources. However, the relative thickness of the medulla accounted for only 59% of the variability among species in concentrating ability, indicating that there are other morphological or physiological factors that significantly influence urine concentrating ability (Beuchat, 1990).

In the present study, the renal cortico/medullary thickness as well as the relative medullary thickness among different studied species were distinctly varied, with the spiny mice had the highest values of RMT followed by the hedgehogs then the guinea pigs which showed the lowest values.

The present data are consistent with the results of Coleman & Downs (2009) and Cooper & Withers (2010) who reported that the relative medullary thickness of the different mammalian species inhabiting arid and semiarid environments was significantly higher in comparison to that of the species inhabiting mesic area. The present findings concerning the relative medullary thickness may be attributed to the different nature of either diet and/or habitat of the studied animals. Such suggestion comes from the study of Casotti *et al.* (2005) who reported that the shift from insectivory to frugivory and nectarivory in bats from different habitats was accompanied by a reduction in RMT, a reduction in the percent of renal medulla, and an increase in the percent of renal cortex. Moreover, close correlation between the relative medullary thickness and the availability of water in the animal's environment has been mentioned by Dickinson *et al.* (2005) and El-Gohary (2009).

The renal papilla of the spiny mice kidney was markedly sharp pointed, longer and extended down into the renal pelvis comparing to the corresponding papillae of both the hedgehogs and the guinea pigs which were relatively shorter and blunt. These results agree with the lengthening of the papilla in case of *G. gerbilus* (Ismail, 1997) and sand rat (El-Bakary, 2000). Also, these observations are parallel to that recorded in the hedgehogs by Altschuler *et al*. (1979). They cited that a broad (blunt) papilla may be necessary to produce a large urine volume, whereas a narrow pointed papilla may be better adapted to concentrate urine down to a small volume.

Moreover, the present data give further support to the view that a slender papilla has been found typical in desert rodents often exposed to conditions of water shortage (El-Gohary *et al*. 2008 and El-Gohary 2009).

In the present investigation, the renal pelvis of the guinea pigs was of simple type. On the other side, the spiny mice and the hedgehogs had very specialized form of renal pelvis. It penetrates the inner stripe with many complexity shaped extensions, which surround the giant vascular bundles.

The kidneys of the different investigated animal species showed three types of nephron populations. The glomeruli of all the nephron populations of the spiny mice kidneys were distinctly smaller than the corresponding glomeruli of both the guinea pig and hedgehog kidneys. The recorded results are consistent with the studies of Dickinson *et al.* (2007) and El-Gohary (2009).

The number of nephrons was varied among examined species; with the hedgehog kidneys had the highest values followed by the guinea pigs then the spiny mice which had the fewest number of nephrons. Such data are in a good agreement with the results obtained by El-Beltagy (2002) who showed that bats inhabiting mesic environment had nearly three times as many nephrons as those living in arid zone. Also, few number of nephrons was recorded in many rodent species inhabiting arid habitats as reported by Altschuler *et al*. (1979) on the pocket mouse, *Perognathus penicillatus* , El-Gohary *et al*.(1992) on *G. gerbilus,* El-Bakary (2000) on *Psammomys obesus*, Dickinson *et al.* (2007) on spiny mice, El-Gohary *et al*. (2008) on insectivorous bats and El-Gohary (2009) on bandicoot rats. Thus the fewer number of nephrons may be considered as an evolutionary trend that favors the elaboration of a small volume of concentrated urine in desert adapted species and subsequently could contribute to a successful water economy (Dickinson *et al*., 2007).

On the other side, kidneys of rodents from mesic environment have relatively high density of glomeruli (El-Beltagy, 2002). Therefore, guinea pigs with a predominantly vegetable diet with high water content need to filter a greater volume of fluid than do spiny mice with a predominantly relatively dry diet with relatively low water content. Thus greater number of nephrons in the guinea pig kidneys may be necessary to handle large volumes of glomerular ultrafiltrate.

The JM/S ratio of glomerular size of the insectivorous hedgehogs was higher followed by the spiny mice and then the guinea pigs. Such findings may lead to preferential filtration in these juxta-medullary nephrons and because they have long loops may result in higher concentrating capacity. The present observations are in agreement with the results of Ismail (1997) who recorded that JM/S ratio for glomerular size was particularly higher in desert than in non desert species.

The total glomerular volumes per gram body weight of the spiny mice was distinctly smaller than those of the guinea pigs and the hedgehogs. Such findings may be attributed to both the fewer number and smaller size of glomeruli in the spiny mice in comparison with the other studied species. Therefore, the relative smaller filtration surface area of the spiny mice may assume certain adaptive considerations, since the glomerular filtration rate (GFR) may be basically depended upon the external surface area of glomeruli.

In the present work, the inner stripe of the outer medullary zone of the spiny mice was markedly developed. It consists of two distinct compartments, that of the giant vascular bundles and that of the interbundle regions. The giant vascular bundles consist of arterial vasa recta, venous vasa recta and the thin descending limbs of the short loops of Henle. The observed data are in agreement with the studies of (El-Bakary (2000) on *Psammomys obesus*, Dickinson *et al.* (2007) on spiny mice, El-Gohary *et al*. (2008) on insectivorous bats and El-Gohary (2009) on bandicoot rats who reported that the inner stripe of the outer medulla of the desert inhabited mammalian species had high frequency of well-developed giant vascular bundles.

The fenestrated endothelial cells, the filtration slits and the glomerular basal lamina formed the filtration barrier, the thickness of which was markedly varied among the examined species. The spiny mice showed the greatest thickness followed by the hedgehogs then the guinea pigs which had relatively thin filtration barrier.

In addition, the spiny mice had relatively low density of narrow filtration slits. However, the guinea pigs showed high density of obviously wide filtration slits comparing to the other species. Similar observations have been recorded on different mammalian species by El-Gohary *et al*. (2008) and El-Gohary (2009). In addition, the present observations are in accordance with the results of Safer *et al.* (1988) who reported that, in an arid habitat in which the organism is subjected to long periods of water deprivation, a thick basal lamina would provide strong mechanical support to the glomerular capillaries against the extremes of the concentration and dilution of the blood and assist in keeping the lumens of the capillary loops open in hypertonic environment of the medullary interstitium. Further confirm of the present observations comes from the findings of Safer *et al*.(1988) on *Meriones crassus*, Ismail (1997) on *Gerbilus gerbilus* and El-Bakary (2000) on *Psammomys obesus.*

The ultrastructure of the epithelial lining of the proximal tubule of the spiny mice showed well developed brush border of numerous long microvilli and fewer small endocytic vesicles, huge numbers of elongated mitochondria with distinct densely packed cristae. In addition, the basal lamina of the proximal epithelial lining of the spiny mice was distinctly thicker compared to those of the hedgehogs and the guinea pigs. These observations go parallel with the findings of Kaissling ***et al.*** (1977) on *Psammomys obesus*, Tsujii ***et al***. (1992) on Platypus and El-Bakery (2000) on sand rat.

The presence of a well developed long microvilli play an important role in the increment of the surface area exposed to the lumen to facilitate the movement of large fluid volumes and to absorb a large proportion of fluid from the glomerular filtrate to maintain water balance of arid inhabitant species as previously reported by Bon & Fawcett (1986).

In the present study, the high density of mitochondria, the well developed basal infoldings of the epithelial lining of the distal tubules of the spiny mice reflects the active site and high degree of electrolyte transport (Kaissling and Le Hir, 1982), since the distal tubules are mainly involved in sodium reabsorption from the tubular fluid as mentioned by Burkitt ***et al***. (1993). These observations are in a good agreement with the findings of Kriz ***et al***. (1978) and Kaissling (1982). Moreover, the markedly thick basal lamina of the epithelial lining of both proximal and distal tubules of the spiny mice support the previous observations of Safer ***et al***.(1988) who reported that the nephron of the one-humped camel ***Camelus dromedarius*** is unique in having an unusually thick basal lamina underlying the epithelial cells of the nephron.

Since the investigated species of the present study inhabit vastly different environments, their osmoregulatory demands are quite different. Thus, the recorded striking differences in the renal morphological, anatomical, histological and ultrastructural aspects between the selected arid - and mesic - zone species are consistent with a need to conserve water and /or ions respectively. However, much more must be learned about the genetic factors which consequently may help in illuminating details of interspecific variations in renal concentrating capacity among mammalian species.

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