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Abstract

Blood vascular beds of fetal, adult and aged human kidneys were reproduced with methyl methacrylate and observed with a scanning electron microscope. The kidney glomeruli, including those from the fetal kidneys, had anastomosing capillaries. The glomeruli in the kidneys of an aged person contained many more capillaries which were much more tortuous than those of the adult and fetal kidneys. Furthermore, it was observed that the glomeruli in the kidneys of the aged person usually received tortuous afferent vessels and frequently emitted multiple efferent arterioles. The glomeruli in the juxtamedullary layer of the kidneys of the aged person were rather small in size and contained degenerative capillary networks. This observation suggests that the medulla of the kidneys of the aged is poorly supplied with blood.

KEYWORDS: scanning electron microscopy, vascular casts, kidney glomerulus, aging, glomerular efferent vessels

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Human Kidney Glomeruli, with Special Reference to Those in the Aged Person: Scanning Electron Microscopic Study of Microvascular Corrosion Casts

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Blood vascular beds of fetal, adult and aged human kidneys were reproduced with methyl methacrylate and observed with a scanning electron microscope. The kidney glomeruli, including those from the fetal kidneys, had anastomosing capillaries. The glomeruli in the kidneys of an aged person contained many more capillaries which were much more tortuous than those of the adult and fetal kidneys. Furthermore, it was observed that the glomeruli in the kidneys of the aged person usually received tortuous afferent vessels and frequently emitted multiple efferent arterioles. The glomeruli in the juxtamedullary layer of the kidneys of the aged person were rather small in size and contained degenerative capillary networks. This observation suggests that the medulla of the kidneys of the aged is poorly supplied with blood.

Key words : scanning electron microscopy, vascular casts, kidney glomerulus, aging, glomerular efferent vessels

The architecture of the kidney glomerular capillaries has been intensively studied in man and various animals by light microscopy of sectioned tissues with or without dye-injection, or cast samples (1-5). However, the conventional light microscope is insufficient for a clear three-dimensional analysis of such conglomerated capillaries as those of the kidney glomerulus because of its limited resolution and shallow focus (6). In contrast, recently developed scanning electron microscopy of vascular casts has overcome the shortcomings of light microscopy and has allowed a clear three-dimensional visualization of blood vascular beds, including those of the kidney glomerulus (6, 7). With this microscopic method conclusive evidence has been obtained that in man, monkeys, rats and other animals, the kidney glomerulus consists of conglomerated tufts of anastomosing capillaries which are intercalated between the afferent and efferent arterioles (7-11). It has been clarified further that in man and some other animals, the kidney glomerulus develops from a single interstitial vessel (10, 16, 17). In this paper the human glomerular capillaries of an aged person observed by the vascular casting/scanning electron microscopic method are described.

Materials and Methods

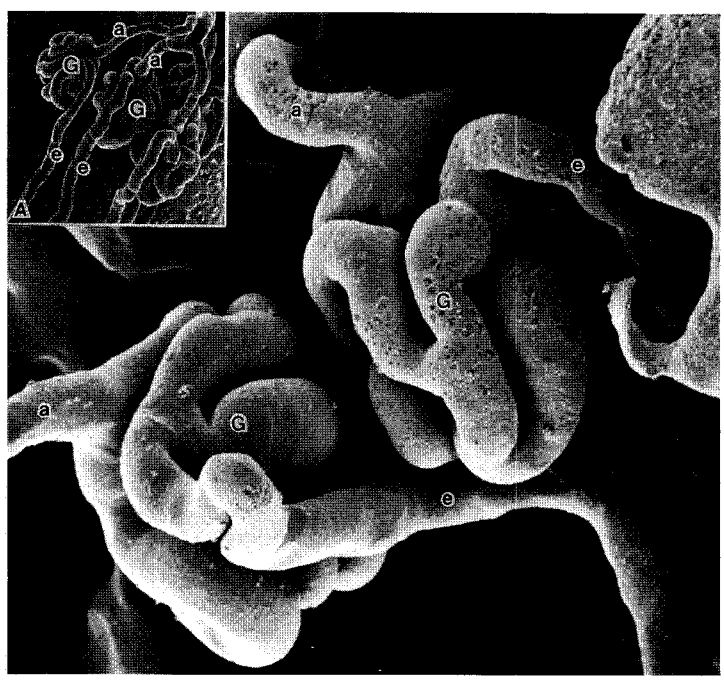
Human kidneys obtained at autopsy from 3 individuals, a male fetus (10 months old, stillborn due to coiling of the umbilical cord), an adult woman (24 years old, died of femoral osteosarcoma)

and a senile man (84 years old, died of gastric cancer), were perfused with physiological saline and then with low viscosity methyl methacrylate media through the renal arteries (6, 12). The infused kidneys were corroded in a hot NaOH solution (10%, 60°C), washed in running tap water, and air dried (6, 12). The blood vascular casts of the kidneys thus prepared were dissected with forceps, and the glomeruli were isolated together with their affiliated afferent and efferent arterioles. The isolated glomerular casts were coated with gold in a vacuum evaporator (IB-3, Eiko) and observed with a scanning electron microscope (HHS-2R, Hitachi) using an acceleration voltage of 5 kv.

Results

Macroscopic examination revealed that none of the specimens showed marked pathological changes, except for a few small blisters in the kidneys of the 84-year-old man. Low viscosity methacrylate media infused through the renal arteries gave good casting of the blood vascular beds of the glomeruli and their affiliated afferent and efferent arterioles in all the specimens (Fig. 1-4). Leakage of the infused media from the glomerular capillaries and their affiliated vessels occurred rarely (Fig. 3). In all of the kidneys, the glomerular capillary tufts were conglomerated.

The kidney glomeruli from the 24-year-old woman were formed by conglomerated tufts of anastomosing capillaries (Fig. 2). Each of these glomeruli received a single afferent arteriole from the interlobular artery and emitted a single efferent arteriole linked to the parenchymal capillaries. It was rather rare that a glomerulus emitted two or more efferent vessels (Fig. 2, Inset B). The larger glomeruli were composed of more capillaries and located in the deeper areas of the kidney (Fig. 2, Inset A). Thus, the hilus or vascular pole of the juxtamedullary glomerulus was almost always widened



Fip. 1 Scanning electron micrograph of a methyl methacrylate cast of a 10-month-old human kidney (mid-cortical layer). Note that the glomerular capillary tuft (G) is conglomerated and contains some capillaries which are intercalated between the afferent (a) and efferent (e) vessels. Inset A shows some juxtamedullary glomeruli (G) intercalated between the afferent (a) and efferent (e) vessels. ×1030, Inset A ×180.

Fig. 2 Scanning electron micrograph of a methyl methacrylate cast of a 24-year-old kidney (subcapsular layer). Note that the glomerulus (G) receives a single afferent arteriole (a) from the interlobular artery (I) and emits a single efferent arteriole (e) continuous with the parenchymal capillaries. Inset A shows juxtamedullary glomeruli (G) whose efferent arterioles (e) are thicker than the afferent arterioles (a). Inset B shows a glomerulus (G) with a single afferent arteriole (a) and two efferent arterioles (e1, e2). ×120, Inset A ×180, Inset B ×100.

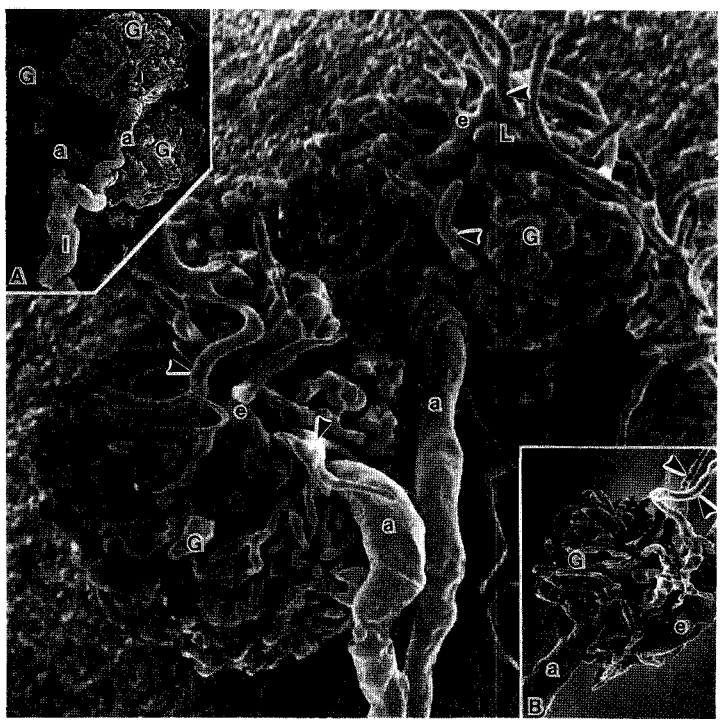


Fig. 3 Scanning electron micrograph of a methyl methacrylate cast of an 84-year-old kidney (mid-cortical layer). Note that the glomerulus (G) emits some accessory efferent vessels (arrowheads), in addition to the normal afferent (a) and efferent (e) vessels. Inset A shows some glomeruli (G) which receive tortuous afferent arterioles (a) from a tortuous interlobular artery (I). Inset B shows a degenerative juxtamedullary glomerulus (G) with two accessory efferent vessels (arrowheads) in addition to the normal afferent (a) and efferent (e) vessels. L, leakage of the infused resin. ×230, Inset A ×150, Inset B ×200.

by the invasion of a part of the well-developed capillary tuft between the afferent and efferent arterioles (Fig. 2, Inset A). Such widening of the hilus was not noted in the glomeruli in the superficial layers of the kidneys (Fig. 2). The afferent arteriole of most glomeruli was usually thicker than the efferent arteriole (Fig. 2). In the juxtamedullary glomeruli, the afferent arterioles, however, were almost always thinner than the efferent arterioles which descended into the renal medulla (Fig. 2, Inset B).

The kidneys of the 10-month-old fetus contained many immature glomeruli throughout the renal cortex and juxtamedullary layers (Fig. 1). These immature glomeruli consisted of a few anastomosing capillaries. and had afferent and efferent vessels of similar calibers. Even in the juxtamedullary glomeruli, the afferent vessels were as thick as the efferent vessels (Fig. 1, Inset A).

The glomerular capillary tufts were much larger with many more capillaries in the kidneys of the 84-year-old man than in those of the 24-year-old woman or fetus (Fig. 1-4). The glomerular capillaries were more tortuous in the kidneys of the aged man (Fig. 1-4), particularly in the mid-cortical layers (Fig. 3, 4). In these layers, the well-developed, markedly tortuous capillaries usually widened the vascular pole of the glomerulus (Fig. 3). In contrast, the juxtamedullary glomeruli were degenerative (Fig. 3, Inset B). These degenerative glomeruli were smaller and contained fewer capillaries than the glomeruli in the cortical areas and also than the juxtamedullary glomeruli of the 24-year-old woman. In such degenerative glomeruli, the efferent vessels were as thick as the afferent vessels, and many discontinuities of the glomerular capillaries were noted. The afferent vessels of the aged glomeruli, including the degenerative ones, were almost always tortuous (Fig. 3, Inset

Fig. 4 An aged human kidney glomerulus (G) with an accessory efferent vessel (arrowhead) (isolated from the mid-cortical layer of the 84-year-old kidney). Note that the glomerulus contains numerous capillaries intercalated between the afferent (a) and efferent (e) vessels. Also note that the efferent vessels (e) shows early branching within the vascular pole. Inset A shows an aged subcapsular glomerulus (G) with normal single afferent (a) and single efferent (e) vessels. ×470, Inset A ×160.

A). In such cases, the interlobular arteries were also tortuous (Fig. 3, Inset A).

In the kidneys of the 10-month-old fetus and 24-year-old woman, the glomerular efferent vessels were rather straight and branched into the parenchymal capillaries outside the vascular pole. In contrast, the glomerular efferent vessels of the 84-year-old man kidneys usually branched irregularly within the vascular pole. Such early branching of the efferent arteriole was exclusively observed in the mid-cortical layer (Fig. 3, 4). Glomeruli with early branching of the efferent arteriole usually emitted two or more accessory efferent arterioles at or near the vascular pole (Fig. 3, 4). The accessory efferent vessels occasionally left the glomerulus near the urinary pole. It was rather rare in the kidneys of the aged man that the glomerulus emitted a straight efferent vessel which branched outside the vascular pole (Fig. 4, Inset A).

Discussion

The present study of vascular casts of the human glomeruli by scanning electron microscopy confirms our previous findings in man, monkeys, rats and other animals that the kidney glomerulus consists of conglomerated tufts of anastomosing capillaries(7-10, 13, 16, 17). Thus, the present study strongly supports the plexus model of kidney glomerular microcirculation proposed by Johnston and others(1-5, 11). The kidney glomerulus has neither non-anastomosing capillaries as contended by Vimptrup(14) nor sacculated capillaries derived from the wall of a single arteriole as claimed by Trabucoo and Marquez(15). Microdissection of the glomerular capillary tufts were omitted in the present study. However, our previous microdissection/scanning electron microscopic studies of the cast samples of man and other animals have clearly shown that the glomerular capillary tufts, both developing and aging ones, are divided into fairly independent lobules or vascular units between the afferent and efferent arterioles (7-9, 13, 16, 17).

It has been shown by scanning electron microscopy of vascular casts of adult bullfrog and 6-month-old human fetal kidneys that the glomerular capillary tuft develops from a single or U-shaped interstitial vessel (10, 16, 17). Such a primitive form of the glomerulus was not encountered in the 10-month-old fetal kidneys observed in this study. This finding suggests that the primitive single vessel is transformed into anastomosing capillaries in an early stage of fetal development.

The present study, together with our previous ones (16, 17), confirms that the glomerular capillaries increase in number from the fetal to aged stages and that the glomerular capillaries become more tortuous as they age. The increase in number and tortuosity of the capillaries may widen the filtration surface of the glomerular capillaries and compensate for decreased functioning of the aged glomerular capillaries. It was noticeable that the aged glomerulus with markedly tortuous capillaries always received a tortuous afferent vessel from a tortuous interlobular artery. High blood pressure may be needed to convey sufficient blood to tortuous interlobular arteries and afferent arterioles and also to maintain sufficient blood flow in aged glomeruli with marked tortuous capillaries.

The present study also shows that in the aged kidney, the juxtamedullary glomeruli, whose efferent vessels descend into the renal medulla, are rather small or degenerative and have fewer capillaries. This observation indicates that the renal medulla of the kidneys of aged persons is poorly supplied with blood. The juxtamedullary layer is

partially supplied by the accessory branches of the juxtamedullary efferent vessels (21). Thus, it is considered that the juxtamedullary layer is also poorly supplied with blood.

The present study confirms that the fully developed glomeruli of the aged kidneys are frequently provided with two or more accessory efferent vessels. It is considered that these accessory efferent vessels are acquired after the development of the glomerulus to convey blood, which is abundant in the fully developed glomerulus, to the parenchymal capillaries. Such double efferent vessels observed in the adult kidneys may be congenital since they are also observed in fetal kidneys. Double efferent arterioles of the glomerulus have also been observed in fetal rat kidneys(7). Boenig described multiple efferent vessels of the human kidney glomerulus (18), but failed to discriminate the early branching of the main efferent arteriole within the vascular pole from the true accessory efferent vessels which arise separately from the glomerular capillary tuft. Our recent study has shown that even the adult kidney glomerulus may have three or more efferent vessels(19).

Ljungqvist described some direct connections between the afferent and efferent juxtamedullary arterioles in transmission electron microscopy of sectioned human samples (20). Such direct connections of the glomerular afferent and efferent vessels were not noted in our cast samples, including those from the 84-year-old man. So-called Ludwig's arterioles, which arise from the interlobular arteries and directly branch into the parenchymal capillaries, were not observed in the present study.

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