Normal kidney development in medaka fish

Fedorova Svetlana
Laboratory of Freshwater Fish Stocks
Bioscience and Biotechnology Center
Nagoya University
Part I

General organization of kidney
Total body water equals approximately 60% of total body weight in young men, about 50% in young women, and less in older persons. Baby’s total body water is between 65% and 75%.

In a 70-kg man, in good conditions, total body water equals 42 Liters.

Water is always circulate in the body, it transport chemicals and “food” to every part of our organisms and take out the wastes.
Kidney: either one of a pair of organs, functioning to maintain proper water and electrolyte balance, regulate acid-base concentration, and filter the blood of metabolic wastes, which are then excreted as urine.

- The excretory systems of vertebrates consist of filtration units that allow small molecules from blood to pass out into the urinary space, specialized transporting cells that selectively recover certain solutes and return them to the blood, and also recover water in many species, and take urine out of the body.
- In humans the total volume of blood filtered by the kidney is about 180 Liters /24 hours. Only about 1 to 1.5 Liter is excreted as urine.
General organization of the human kidney

- **Cortex** - the outer part of the kidney, it consists of glomeruli.
- **Medulla** - part of the kidney, where water and salts reabsorption occurs.
- **Ureter** - either of a pair of thick-walled tubes that carry urine from the kidney to the urinary bladder.

Basic Histology: text and atlas
The functional units of the kidneys - nephrons, glomerulus, proximal and distal tubules

- Nephron-, the functional units of kidney. The nephron consists of three major components: the glomerulus, the renal tubule, and the collecting duct.
- Glomerulus is responsible for blood filtration.
- Renal tubules (proximal and distal tubules) extend from the glomerulus to its junction with the collecting duct. It is lined by a single layer of epithelial cells that function in selective reabsorption of water, inorganic ions, and other molecules from the glomerular filtrate.
- Collecting duct communicates with the exterior and serves as the exit channel for the remaining waste products.

Basic Histology: text and atlas
Urea concentration

Atlas of Kidney Diseases
Renal corpuscle - glomerulus

glomerulus - a small group of capillaries, covered by special cells, podocytes; glomeruli filter blood during urine formation.
Podocytes

- Glomerular capillary is highly fenestrated.
- Capillary is covered by podocytes – special cells that have many “legs”. Urea filtration occurs between podocyte “legs”

Basic Histology: text and atlas
Types of kidneys.

There are 3 types of kidneys: pronephros, mesonephros and metanephros.

This terminology can be confusing, but you should be able to keep the order of formation straight if you remember that *pro* means "first", *mes* means "intermediate" and *meta* means "beyond" or "later".
Pronephros - most primitive of the three vertebrate kidneys, active in the adults of some primitive fish (lampreys and hagfish), the embryos of more advanced fish, and the larvae of amphibians. It is a paired organ consisting of a series of nephrons that filter urine.

The zebrafish pronephros. (A) Diagram of the larval pronephros at 72 hours postfertilization.

(B) Special staining of a 84 hours embryo shows the anatomy of the pronephros. Pt – pronephric tubules, PD – pronephric duct.
**Mesonephros** - permanent kidney of amphibians and most fish, developing posterior to and replacing the pronephros of the embryonic and larval stages. It is a paired organ consisting of a set of nephrons having capsules, that filter blood from the glomerulus and tubules, whose cells reabsorb water and nutrients and secrete nitrogenous wastes.

**Metanephros** - permanent kidney in reptiles, birds, and mammals, developing by the 10th week in human embryos and replacing the embryonic structure called the mesonephros. During their development, mammalians go through all types of kidney:

pronephros is generated first, then it degenerated and mesonephros is formed. Only after that metanephros will replaced mesonephros
Part II: Kidney in medaka fish

- Model organisms, including the medaka, allow for experimental analysis of kidney function and the detailed characterization of disease processes.

In the medaka fish, kidney development progresses from the simple pronephros to the more complex mesonephros.
Pronephros in medaka fish:

In medaka, the functional pronephros consists of only two nephrons with glomeruli fused.

- Medaka embryo of 1 day of development. Special staining reveals place of future pronephros. Photo: R. Miyamoto.

- 2-days old medaka embryo. Pronephric kidney begins to develop on the second day of embryogenesis. Photo: R. Miyamoto.
Medaka’s pronephros

- Pronephros is mostly formed on the 4th day of embryo development, and finally formed on the 5th day.

Photo: R. Miyamoto
Mesonephros.

- First mesonephric glomerulus appears approximately on 5th day after fish hatching. Photo: R. Miyamoto

- Glomerulogenesis in medaka is continued during “baby” stage. Photo: R. Miyamoto
Kidney in adult medaka

The normal kidney in adult medaka consists of two parts, which are located separately.

Each adult medaka kidney consists of approximately 250 glomeruli, which are uniformly distributed through whole kidney length. 3-dimensional reconstruction.
Glomerulogenesis in medaka is continued during fry stage and early adulthood. The most glomeruli had generated to the age of 3-month old.

Glomeruli size is increased during all fish life.
Human kidney diseases

One of the most common human genetic diseases is polycystic kidney disease (PKD), which affects 1 in 1000 individuals. Kidney cysts are the result of grossly expanded kidney tubule transport.

Polycystic kidney disease (PKD) leads to massive kidney enlargement by the cystic dilation of renal tubules and chronic renal failure.

The picture of patient with PKD. It is evident that the morphology of left kidney is grossly abnormal. What is more striking, is the enlarged left kidney that clearly demonstrates cysts (outlined by arrows).

In some cases renal transplantation can save these patients' lives.
Medaka model of human kidney diseases

Although simple in form, the medaka’s kidney is composed of cell types that are typical of human kidneys, including fenestrated capillary, podocytes, and polarized tubular epithelial cells.

Model organisms, including the medaka, allow for experimental analysis of kidney function and the detailed characterization of disease processes.
Medaka polycystic kidney disease

Medaka polycystic mutant (PC) was found as a naturally occurred mutant in 1975. It was collected by Tomita and then maintained in the laboratory. Medaka pc mutant develops a kidney disorder in the mesonephros.

- **External appearance of pc mutant.** (A and B) normal. (C and D) pc mutant.

- (E and F) See-through madaka stock. (G and H) pc see-through medaka stock. Arrows indicate the range of the cystic kidney. The bar represents 5 mm, which is applied to all panels. Abbreviations are: ab, air bladder; b, brain; g, gill; h, heart; i, intestine; k, kidney; l, liver; s, spleen; sp, spinal cord.

Normal kidney section

Polycystic kidney section

cysts

Conclusions

Despite some differences in organ morphology between the human and medaka kidneys, many parallels exist at the cellular and molecular levels that can be exploited to further our understanding of kidney development and disease.

The same mechanisms and cell types are used in the development and function of both medaka and human kidneys.

Many hereditary kidney diseases are common for medaka fish and humans.

The medaka presents a useful model for studies of kidney development and disease.
References:


Atlas of Kidney Diseases // Edited by Tomas Berl and Joseph V. Bonventre

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