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# Blood Pressure and Kidney Function

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# Blood Pressure and Kidney Function

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*The physical and chemical processes involved in the functioning of the kidneys are reconsidered. It is shown that the transfer of fluid into the Bowman capsule of the nephrons is a gate transfer process and not a filtering process. The principle function of the kidneys is demonstrated as the control of the concentration of metabolically produced protein in blood by hydrolysis. This function is directly linked to the value of blood pressure. The origin and distribution of compounds produced in the kidneys is discussed.* ***J Clin Basic Cardiol 2008; 11 (online): 11–5.***

***Key words:*** *flow rate, gate control, hydrolysis*

The kidneys perform several functions, first, the removal of unwanted or deleterious chemical compounds from the blood flow while preserving and returning to the blood flow essential compounds already present in the blood flow (tubular function). The second function of the kidneys is the production and transfer into the blood flow of essential compounds not present in the blood flow (endocrine function). In addition, the kidneys are involved in the control of blood pH value. The present concept of the physical operation of the kidneys involves the transfer of fluid from the capillaries of the glomerulus into the nephrons. This process is proposed as filtering out most of the large components present in blood such as blood cells and some proteins. Most of the fluid and many of the compounds and ions present in the fluid entering the nephrons through the Bowman capsule are considered to leave the nephron and return to the blood flow. The remainder exit the metabolism in urine. The separation process is considered to depend on the physical processes of filtration, diffusion, osmotic migration of water and chemical reactions. The movement of water under blood and osmotic pressure differences and ion diffusion under concentration gradients are the factors advanced as influencing the operations in kidneys.

Several observations are not in keeping with the above hypothesis of kidney operations. The concentrations of organic compounds and dissolved inorganic ions in serum and urine (Tab. 1) demonstrate that the operation of the kidneys results in an increase in the concentration of K+ and $PO4^{3-}$ ions in urine to values which are above those in serum and intercellular fluid although not as high as those present in the intracellular fluid. This change cannot take place by osmotic transfer or a simple filtration process and can only arise as the result of the entry into the nephrons of intracellular fluid or complete cells, which contain a higher concentration of these ions. The presence of a considerable range of amino acids and few intact proteins in urine (Tab. 2) demonstrates that hydrolysis of proteins in blood entering the nephrons occurs in the kidneys. In addition, serum is a colloidal hydrophilic fluid and urine is an aqueous solution. It follows that one function of the kidneys is the arrangement of this conversion. The work below presents a revision of the present hypothesis of kidney function which resolves these difficulties and leads to a link between blood pressure and kidney function.

## The Physical Process Involved in Nephron Operation

Arteries, arterioles, venules and veins are formed as a layer of cells backed by a layer of elastic tissue. The latter is, in turn, backed by a sheet of muscle tissue composed of multilayers of muscle cells. In the case of capillaries, the layer of cells lining the capillary wall is considered to be reduced to one layer in thickness. The cells involved are not linked or permanently in close contact. Under the continuous pressure in the blood circulation such a layer would allow continuous leakage of blood into the Bowman capsule without filtration. To form a barrier to such a leakage requires that the layers of elastic and/or muscle tissue form a continuous linkage between the arterioles and venules. On this basis, the contraction and expansion of the capillaries will extend or contract this tissue. The highly convoluted form of the capillaries in this unit magnifies this effect. This movement enlarges and diminishes the size of any pores present in the tissues. The operation allows the passage of fluid and components of blood into the Bowman space. The transfer of fluid from the blood flow into the glomerulus is therefore better described as gate controlled process since this does not imply filtration. Blood flow is pulsed and the pressure in the blood flow varies from a high value of about 120 mmHg (systolic) to a low value of about 80 mmHg (diastolic). The pores are opened by the passage of a pulse of blood expanding the capillaries and closed by elastic contraction when the pulse has passed. Under these conditions, the pore size is not uniform and not endlessly reproducible. This precludes the application of laws of filtration where the pore size is taken as invariant. In the expanded state, the pores are open and contact is made between the blood and the fluid in Bowman space. Fluid is injected (squirted) into the Bowman space filled with fluid from the previous open state by the hydraulic pressure in the blood circulation. This results in fluid being injected into the nephron. The movement of fluid through the nephrons is therefore pulsed. In the contracted state, the pores are closed and the pressure in the nephron system falls.

A second source of fluid flow exists in the kidneys. The ureter connecting the kidney to the bladder has a length of between 25 and 30 cm and represents a column of liquid. Any column of liquid above ground level generates a pressure and pressure is uniform irrespective of any changes in diameter throughout the column length. When full of fluid the hydrostatic pressure exerted by the column is given by $h\rho g$ where h is the height of the top of this column above ground level, $\rho$ is the fluid density and g is the acceleration of gravity. The value of h for the ureter latter is dependent on physical characteristics being about 36 inches (92.2 cm) above ground level for an individual six feet in height in the vertical stance. A column of water of 1041.2 cm in height and a column of mercury of 76 cm in height are one atmosphere pressure. The density of urine varies in the range of 1.002–1.028 gm per ml. From this the ureter column when full will exert a downward pressure of 67.4–69.2 mmHg. In the verti-

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**Table 1.** The ion content of metabolic fluids. Source [1, 2]

| Ion | Intracellular concentration (mmol/l) | Intercellular concentration (mmol/l) | Serum concentration (mmol/l) | Urine concentration (mmol/l) | Glomerular filtrate concentration (mmol/l) |
|---|---|---|---|---|---|
| Na+ | 10 | 140 | 144.5 | 151.7 | 142 |
| K+ | 140 | 4 | 4.83 | 47.9 | 5 |
| Ca 2+ | 1.5 | 2.5 | 2.31 | 2.1 | |
| Mg 2+ | 12.5 | 1 | 0.96 | 2.1 | |
| Cl– | 2 | 105 | 109.17 | 153.1 | 103 |
| PO4– | 31.7 | 0.67 | 0.97 | 7.6 | |
| HCO3 2– | 4 | 12.5 | 21–27 | — | 28 |
| SO4 2– | 12.5 | 0.5 | — | — | |
| **Compounds (mg/ml)** | **Intracellular concentration (mmol/l)** | **Intercellular concentration (mmol/l)** | **Serum concentration (mmol/l)** | **Urine concentration (mmol/l)** | **Glomerular Filtrate concentration (mmol/l)** |
| Creatinine | — | | 0.0935 | 7.7 | 0.11 |
| Glucose | — | | 5.2 | — | 1 |
| Urea | — | | 4.03 | 208.4 | 0.26 |
| Albumin | — | | 32–56 | | |
| Cholesterol | — | | 1.5–2.5 | | |
| Protein | 55 | 12 | 39–50 | | 0.06–0.11 |
| Uric acid | — | — | 0.02–0.075 M<br>0.02–0.065 F | | 0.03 |

M = male; F = female

**Table 2.** The compounds present in metabolic fluids

| Common to blood and urine | Blood only | Urine only |
|---|---|---|
| Alanine | Anserine | Benzoate |
| c-Amino butyric acid | a-Amino-N-butyric acid | Cis-aconite |
| Ammonia | Carnosine | Citrate |
| Arginine | Cystathionine | Creatine |
| Aspargine | Ethanoamine | Cysteine |
| Aspartic acid | Hydroxylysine | Fumarate |
| Citrulline | 1-Methyhistidine | Glutarate |
| Creatinine | 3-Methyhistidine | Gluthione |
| Glutamic acid | Ornithine | Glycolate |
| Glutamine | Phosphoethanolamine | Hippurate |
| Glycine | Sarcosine | Homovalinate |
| Homocysteine | | a-Hyroxybutarate |
| Hydroxyproline | | 5-Hydroxyindolacetate |
| Histidine | | Hydroxymethyglutarate |
| Isoleucine | | p-Hydroxyphenlyacetate |
| Leucine | | Isocitrate |
| Lysine | | a-Ketoglutarate |
| Methionine | | a-Keto-iso-caproate |
| Phenylalanine | | a-Keto-iso-valerate |
| Phospherine | | Lactate |
| Proline | | Malate |
| Serine | | 2-Methylhippurate |
| Taurine | | Methylmalonate |
| Threonine | | Orotate |
| Tryptophan | | Pyroglutamate |
| Tyrosine | | Pyrovate |
| Urea | | Succinate |
| | | Sulphate/creatine ratio |
| | | Uric acid |
| | | Valine |
| | | Vanilmandelate |
| | | Xanthurenate |

cal position, this pressure is directed downwards and results in the flow from kidneys to the bladder which refills the bladder after emptying and draws fluid from the nephrons, the induced rate of flow in this case being about half the rate induced by the 120 mmHg pressure present in the blood circulation. This fluid flow is aided by muscular activity. In the supine position, the ureter is largely horizontal. Nevertheless, the column of fluid still gives rise to a hydrostatic pressure directed downwards. The value of height used to estimate the ureter pressure has decreased from 92.4 cm to about 23 cm, giving a value of the hydrostatic pressure of approximately 16.8 mmHg. Although this pressure is directed vertically downwards in the supine position the effect of assisting fluid flow from the kidneys is not reduced to zero. This arises from the fact that the ureter is a flexible tube and some sections will not be entirely horizontal under the effect of gravity. Under these circumstances there will be a resolved pressure value acting along the length of the ureter and the rate of fluid flow decreases but does not stop. The two sources of pressure ensure a continuous although varying flow through each nephron.

The normal means of obtaining the rate of fluid flow through the nephrons in the kidneys is by use of measured creatinine concentration in plasma and urine. The results of this procedure are expressed as the glomerular filtration rate (GFR) [3]. Blood enters and leaves each glomerulus as a continuous flow indicating that only part of this flow enters each nephron and this is represented by the GFR value. For example, an individual exhibits a measured serum concentration of creatinine of 0.01 mg per ml and a measured excretion rate of creatinine of 75 mg per hour in the urine. A typical volume of blood is 5 litres containing 0.01 mg per ml, giving a total of 50 mg. To obtain 75 mg in the urine per hour passage of 7.5 litres per hour of fluid derived from blood through the total of nephrons is required. This means that the rate of fluid flow through the nephrons is 125 ml per minute, equal to 2.08 ml per second. The total number of nephrons in two kidneys is given as $1.5 \times 10^6$ [4] giving a flow rate through each nephron of $8.3 \times 10^{-5}$ ml per minute. As advanced

above, the Bowman space and the nephrons are only filled with fluid when the pores in the glomerulus are open and the flow through the nephrons is pulsed. The pore opening rate is defined by the pulse rate which is normally 72 beats per minute equivalent to a beat every 0.8 seconds. The duration of the open period of the pulse is defined by the duration of the systolic pulse which has a value of 0.36 seconds [5]. In these circumstances, the apparent measured flow through the nephrons (2.08 ml per second) is the measure of the rate that fluid from the blood stream is injected into the nephrons at each pulse that is 2.08 ml per 0.36 seconds equal to 5.78 ml per second or 347.3 ml per minute. This value represents the rate of flow of blood through the glomerulus and is in good agreement with the accepted value for this rate of blood flow of 420 ml per minute per 100 gm of kidney weight. From this 2.08 ml enter the total of the nephrons every pulse beat (0.8 seconds) equal to 2.6 ml per second. This volume fluid transports 0.026 mg of creatinine. The entry of 75 mg of creatinine requires 48 minutes. This value is in reasonable agreement with the measured value of 75 mg per hour. In the event that the pulse rate of an individual either increases or decreases the flow of fluid to the nephron will be affected. An increase results in a shorter pulse duration time and in a shorter filling time and a decrease leads to longer pulse duration time and to a longer filling time. Regulation of the glomerular filtration rate is by the number and expanded area of the pores involved, both of which can alter or can be altered.

## The Chemical Process Involved in Nephron Operation

Serum is a hydrophilic colloidal fluid. The conversion of serum hydrophilic colloidal fluid to the urine aqueous fluid requires hydrolysis of the proteins present in serum. The reduction of protein content in the serum destabilises the hydrophilic colloidal fluid giving rise to an aqueous solution which is the basis of urine. This means that an effective hydrolysing agent is present in serum or is generated by the cells of the nephrons and/or the kidney duct cells. Phosphate ion is the dominant ion in metabolic cells (Tab. 1). The majority of phosphates are insoluble, e.g. calcium phosphates composing bones. This means that in cells phosphate ion exists in a soluble form. The phosphates of sodium and potassium are soluble and readily adopt complex forms. The next most dominant ion in cells is potassium and from the concentration values given in Table 1 0.15 mole of potassium ion requires 0.05 mole of phosphate ion to form the potassium orthophosphate K3(PO4). The concentration of phosphate ion in cells is in excess of this requirement. Other possible phosphates are potassium dihydrogen phosphate (KH2PO4) and dipotassium hydrogen phosphate (K2HPO4). These compounds possess a strong tendency to form poly-forms, and polyphosphates have been identified in cells [6]. Adenine triphosphate is found in all cells and is a salt of polyphosphoric acid. These observations indicate that phosphate ion exists in cells as polyphosphoric acid. Polyphosphoric acid exists in several forms one of which is shown in Figure 1 [7]. All forms of this acid can donate and extract water to and

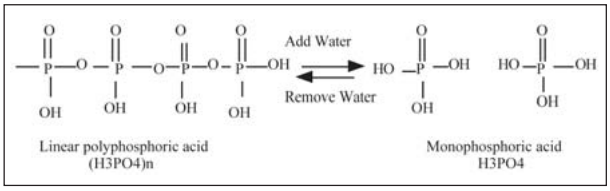


**Figure 1.** Hydration-dehydration of polyphosphoric acid. Derived from [7, 8]

from other compounds (dehydration/hydration agent). DNA, RNA and proteins are all formed by linkage of amino acids by extraction of water. When the cell conditions result in monophosphoric acid being the stable form, hydrolysis of proteins occurs giving amino acids and polyphosphoric acid. When the latter is the stable form, dehydration of amino acids occurs giving proteins and monophosphoric acid. The conditions in a given fluid (pH value, temperature, nature and concentration of cations present) are the factors which decide whether monophosphoric or polyphosphoric acid is the stable form [7]. Under the conditions of varying pore size described above a fraction of the cells in the blood and also a fraction of the larger proteins are forced through the capillaries into the Bowman space by the hydraulic pressure in the blood circulation. This process physically ruptures these cells. The components of the cell intracellular fluid enter the nephron leading to the observation that intact cells are not found in the glomerulus filtrate. The process increases the concentration of mono- and polyphosphoric acid in the nephron fluid above that normally present in blood. The increase originates from the intracellular fluid of ruptured cells in which the concentration of phosphate ion is higher than that present in blood. As this fluid passes through the nephrons the monophosphoric acid hydrolyses proteins, glycoproteins and polysaccharides producing amino acids, monosaccharides and polyphosphoric acid. The reduction of protein content in the serum destabilises the serum hydrophilic colloidal fluid entering the nephrons, giving rise to an aqueous saline solution containing free amino acids and other ions and compounds. This is the basis of urine. The aqueous solution results in the reformation of monophosphoric acid from the polyphosphoric derived from hydrolysis which further reduces the protein content of the fluid. The chemical compounds present in blood and urine are shown in Table 2. This demonstrates that urine contains a greater variety of compounds than is the case for blood, including amino acids derived from hydrolysed proteins.

It is also observed that operation of the kidneys results in an increase in the concentration of K+ and $PO4^{3-}$ ions, demonstrating the presence of one of the phosphates listed above. The sodium ion concentration in urine derives from that in the intercellular fluid and potassium ion concentration derives from the intracellular fluid from the degraded cells. The concentration of the inorganic ions and free amino acids in the aqueous solution formed in the nephrons is higher and the protein content is lower than that in the intracellular hydrophilic colloidal fluid. The aqueous solution formed in the nephrons is physically separated from the intercellular fluid and the blood flow by tissue and cell membranes. Under these conditions water will equilibrate between these fluids by osmosis. The principal driving force in this instance is the difference in the protein and saccharide concentration between the fluids. From this the hydrolysis cycle also contributes to the reduction of the water content of the glomerulus filtrate. The pH of blood is alkaline (pH range 7.35–7.45) and is controlled by sodium carbonate-bicarbonate ion exchange [9]. The mono- and polyphosphoric acids convert these compounds to phosphates releasing carbon dioxide gas. The latter dissolves in the aqueous solution present in the nephrons and leaves the metabolism. This process controls blood acidity. Uric acid is considered to be the final product of the degradation of purines derived from DNA and RNA. It is also observed that the xanthurenate is found in urine but not in blood. This indicates that, in serum, the rate of degradation of cells leading to the formation of uric acid and other degradation products of nucleic acids is low. As proposed above the passage from blood into nephrons results in cell rupture and degradation of the released nucleic acids occurs

**Table 3.** The effect of blood density increase on blood pressure

| Density (gms ml-1) | Increase in density (%) | Revised density (gms ml-1) | Heart level hydrostatic pressure (mmHg) | | Head level hydrostatic pressure (mmHg) | |
|---|---|---|---|---|---|---|
| | | | normal | corrected | normal | corrected |
| **Plasma** | | | | | | |
| 1.025 | 0 | 1.025 | 80.148 | 82.15 | 123.3 | 126.38 |
| 1.025 | 0.1 | 1.026025 | 80.148 | 82.23 | 123.3 | 126.50 |
| 1.025 | 0.2 | 1.02705 | 80.148 | 82.31 | 123.3 | 126.63 |
| 1.025 | 0.3 | 1.028075 | 80.148 | 82.39 | 123.3 | 126.76 |
| 1.025 | 0.4 | 1.0291 | 80.148 | 82.48 | 123.3 | 126.88 |
| 1.025 | 0.5 | 1.030125 | 80.148 | 82.56 | 123.3 | 127.01 |
| 1.025 | 0.6 | 1.03115 | 80.148 | 82.64 | 123.3 | 127.14 |
| 1.025 | 0.7 | 1.032175 | 80.148 | 82.72 | 123.3 | 127.26 |
| 1.025 | 0.8 | 1.0332 | 80.148 | 82.80 | 123.3 | 127.39 |
| 1.025 | 0.9 | 1.034225 | 80.148 | 82.89 | 123.3 | 127.51 |
| 1.025 | 1 | 1.03525 | 80.148 | 82.97 | 123.3 | 127.64 |
| 1.025 | 2 | 1.0455 | 80.148 | 83.79 | 123.3 | 128.91 |
| 1.025 | 3 | 1.05575 | 80.148 | 84.61 | 123.3 | 130.17 |
| 1.025 | 4 | 1.066 | 80.148 | 85.43 | 123.3 | 131.43 |
| 1.025 | 5 | 1.07625 | 80.148 | 86.25 | 123.3 | 132.70 |
| **Whole Blood** | | | | | | |
| 1.06 | 0 | 0 | 80.148 | 84.95 | 123.3 | 130.69 |
| 1.06 | 0.1 | 1.06106 | 80.148 | 85.04 | 123.3 | 130.82 |
| 1.06 | 0.2 | 1.06212 | 80.148 | 85.12 | 123.3 | 130.95 |
| 1.06 | 0.3 | 1.06318 | 80.148 | 85.21 | 123.3 | 131.09 |
| 1.06 | 0.4 | 1.06424 | 80.148 | 85.29 | 123.3 | 131.22 |
| 1.06 | 0.5 | 1.0653 | 80.148 | 85.38 | 123.3 | 131.35 |
| 1.06 | 0.6 | 1.06636 | 80.148 | 85.46 | 123.3 | 131.48 |
| 1.06 | 0.7 | 1.06742 | 80.148 | 85.55 | 123.3 | 131.61 |
| 1.06 | 0.8 | 1.06848 | 80.148 | 85.63 | 123.3 | 131.74 |
| 1.06 | 0.9 | 1.06954 | 80.148 | 85.72 | 123.3 | 131.87 |
| 1.06 | 1 | 1.0706 | 80.148 | 85.80 | 123.3 | 132.00 |
| 1.06 | 2 | 1.0812 | 80.148 | 86.65 | 123.3 | 133.31 |
| 1.06 | 3 | 1.0918 | 80.148 | 87.50 | 123.3 | 134.61 |
| 1.06 | 4 | 1.1024 | 80.148 | 88.35 | 123.3 | 135.92 |
| 1.06 | 5 | 1.113 | 80.148 | 89.20 | 123.3 | 137.23 |

Physical height = 5' 6"; total blood volume = 5000 ml

in the nephrons. These observations support the proposed transfer mechanism and that hydrolysis is the principal chemical reaction in the kidneys.

Four principal chemical compounds are produced in the kidneys. These are the proteins renin, erythropoietin plus calcitriol and prostaglandin. The compounds are present in both serum and urine at low concentrations (picograms per ml) [10, 11]. From the above these compounds are produced by nephron cells and the duct cells from compounds present in the glomerular fluid entering the nephrons and the fluid entering the ducts from the nephrons. The compounds leaving the cells enter both the intercellular fluid surrounding the nephrons and duct cells and the glomerulous fluid. In the former case the compounds transfer into the blood vessels situated in close proximity to the nephrons and ducts. In the latter case the compounds are hydrolysed like all other proteins in the nephron fluid and do not normally appear or only appear in low concentrations in urine.

## Conclusions

Entry of fluid into the nephrons from the blood circulation is by a gate mechanism which gives rise to permeability of the capillaries in the glomerulus. The pulsed nature of cardiac operation means that the capillary permeability is not fixed at a particular value at any particular time over a lifetime for any given individual. The protein albumin is found in urine indicating that this protein passes into the nephrons. The loss of albumin in urine varies in the range from 30.0–100.0 mg per day. The variation in these values supports the conclusion that the permeability of the tissue of the glomerulus capillaries can vary as proposed.

The reason that few proteins are found in urine is that all proteins in the fluid entering the nephrons are hydrolysed giving amino acids. The hydrolysis agent is monophosphoric acid giving rise to polyphosphoric acids. It is known that laboratory hydrolysis of proteins requires a high concentration (6 N) of aqueous hydrochloric acid used at 110 °C whereas metabolic protein hydrolysis takes place at 37 °C in a hydrophilic colloidal fluid. Although hydrochloric acid does not chemically degrade proteins the equivalent hydrolysis reaction to that of the phosphoric acids involves a change in the nature of hydrochloric acid which occurs at the higher temperature. To use monophosphoric acid in protein laboratory hydrolysis would require that the polyphosphoric acid formed is removed from the reaction zone as otherwise an equilibrium is attained and the reaction slows or ceases. This limitation does not occur in the metabolism as the polyphosphoric acid is used in other associated metabolic functions.

Changes in metabolic phosphorus and potassium are recorded as being involved in kidney degeneration supporting the above mechanism [12, 13].

Changes in the mono- and polyphosphoric acid concentration in the nephron fluid above that which is normal for a given individual will induce metabolic change. An increase gives rise to an increased rate and degree of hydrolysis of proteins. The observed effect will be a lowering of the blood pressure as the result of a decrease in blood density [14]. An increase in the production of metabolic proteins or a decrease in the degree of hydrolysis of protein entering the nephrons will result in an increase of these compounds in both the urine and blood. In this case, an increase in blood density occurs. This has the effect that the pressure produced by the heart has to increase so that the blood flow reaches the top of the head [14]. This appears as an increase in measured blood pressure as shown in Table 3 and calculated as previously described [14].

In the cases where glycoproteins and polysaccharides are present in the blood flow changes in the mono- and polyphosphoric acid concentration in the nephron fluid above that which is normal for a given individual gives rise to an increased rate and degree of hydrolysis with the result of increased transfer of monosaccharides to the blood flow. The control of the concentration of these compounds in the metabolism is through reaction with insulin protein. Monosaccharides are more soluble in aqueous fluid than polysaccharides, giving rise to the appearance of these in urine. A decrease in the mono- and polyphosphoric acid concentration in the nephron fluid gives rise to reduced rates and degrees of hydrolysis of glycoproteins and polysaccharides in the blood flow. In the first instance this will again result in an increase in blood pressure, as described above and accumulation of these compounds in the nephrons. The latter change will ultimately give rise to physical blockage of the nephrons by glycoproteins and polysaccharides and/or insoluble derivatives of these compounds.

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