3 RENAL CLEARANCE

Renal Block
At the end of this session, the students should be able to:

- Describe the concept of renal plasma clearance
- Use the formula for measuring renal clearance
- Use clearance principles for inulin, creatinine etc. for determination of GFR
- Explain why it is easier for a physician to use creatinine clearance Instead of Inulin for the estimation of GFR
- Describe glucose and urea clearance
- Explain why we use of PAH clearance for measuring renal blood flow
Mind map

Renal Clearance

Calculation of tubular reabsorption or secretion from renal clearance

Concept of clearance
  - Clearance Equation
  - Clearance tests
  - The importance of renal clearance

Filtration fraction

Glucose clearance
  - Tubular transport maximum for glucose

Criteria of a substance used for GFR measurement
  - Glomerular filtration rate
  - Renal blood flow
  - Renal plasma flow

Criteria of a substance used for RPF measurement
Concept of clearance

Clearance is the volume of plasma that is completely cleared of a substance each minute.

Clearance Equation

\[ C_X = \frac{(U_X \times V)}{P_X} \]

where

\( C_X \) = Renal clearance (ml/min)
\( U_X \times V \) = excretion rate of substance X
\( U_X \) = Concentration of X in urine
\( V \) = urine flow rate in ml/min
\( P_X \) = concentration of substance X in the plasma

The important of renal clearance

- Rate of glomerular filtration
- Assess severity of renal damage
- Tubular secretion & reabsorption of different substances.

Clearance tests

<table>
<thead>
<tr>
<th>endogenous</th>
<th>Urea</th>
<th>Uric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>creatinine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>exogenous</th>
<th>Para amino hippuric acid</th>
<th>Diodrast (di-iodo pyridone acetic acid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inulin</td>
<td></td>
<td></td>
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</table>
Measurement of glomerular filtration rate (GFR)

GFR is measured by the clearance of a glomerular marker like Creatinine & Inulin.

Measurement of renal plasma flow (RPF)

RPF can be estimated from the clearance of an organic acid Para-aminohippuric acid (PAH).

Measurement of renal blood flow (RBF)

RBF is calculated from the RPF and hematocrit.

The formula used to calculate GFR or RPF is:
\[ C_x = \frac{(U_x \times V)}{P_x} \]

X could be PAH, creatinine and inulin.

The formula used to calculate RBF is:

\[ RBF = \frac{RPF}{1 - Hct} \]

Or

\[ RBF = \frac{RPF\%}{100 - Hct} \]

Hematocrit is the fraction of blood volume that is occupied by red blood cells and 1-Hct or 100-Hct is the fraction of blood volume that is occupied only by plasma.
<table>
<thead>
<tr>
<th>Criteria of a substance used for GFR measurement</th>
<th>Criteria of a substance used for renal plasma flow measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. freely filtered</td>
<td>1. freely filtered</td>
</tr>
<tr>
<td>2. not secreted by the tubular cells</td>
<td>2. rapidly and completely secreted by the renal tubular cells</td>
</tr>
<tr>
<td>3. not reabsorbed by the tubular cells.</td>
<td>3. not reabsorbed</td>
</tr>
<tr>
<td>4. should not be toxic</td>
<td>4. not toxic</td>
</tr>
<tr>
<td>5. should not be metabolized</td>
<td>5. and easily measurable</td>
</tr>
<tr>
<td>6. easily measurable</td>
<td></td>
</tr>
</tbody>
</table>
Examples of a substance used for GFR measurement

1. Creatinine (endogenous):
   by-product of skeletal muscle metabolism

2. Inulin (exogenous):
   It is a polysaccharide with a molecular weight of about 5200 and it fits all the requirements.

   If the concentration of Inulin in the urine and plasma and the urine flow are as follows:
   - Conc. of inulin in urine = \(U_{\text{inulin}}=120 \text{ mg/ml}\)
   - Urine flow = \(V=1 \text{ ml/min}\)
   - Conc. of inulin in arterial blood = \(P_{\text{inulin}}=1 \text{ mg/ml}\)

\[C_{\text{inulin}} = \frac{(120 \times 1)}{1} = 120 \text{ ml/min}\]
Why it is easier for a physician to use creatinine clearance Instead of Inulin for the estimation of GFR?

Because measurement of creatinine clearance does not require intravenous infusion into the patient, this method is much more widely used than inulin clearance for estimating GFR clinically. However, creatinine clearance is not a perfect marker of GFR because a small amount of it is secreted by the tubules (error1), so the amount of creatinine excreted slightly exceeds the amount filtered. There is normally a slight error in measuring plasma creatinine that leads to an overestimate of the plasma creatinine concentration (error2), and fortuitously, these two errors tend to cancel each other. Therefore, creatinine clearance provides a reasonable estimate of GFR.
1. Para-aminohippuric acid (PAH)

90% of plasma flowing through the kidney is completely cleared of PAH.

**Question?**

If the concentration of PAH in the urine and plasma and the urine flow are as follows:
- Conc. of PAH in urine = \( U_{\text{PAH}} = 5.85 \text{ mg/ml} \)
- Urine flow = \( V = 1 \text{ ml/min} \)
- Conc. of PAH in arterial blood = \( P_{\text{PAH}} = 0.01 \text{ mg/ml} \)
- Hematocrit is 45% = \( PCV = 0.45 \)

**Effective PAH or Renal Plasma Flow =**
\[
C_{\text{PAH}} = (5.85 \times 1)/0.01 = 585 \text{ ML/min}
\]

**Actual PAH or Renal Plasma Flow =**
\[
585/0.9 = 650 \text{ ML/min}
\]

**Renal blood flow =**
\[
650/(1-0.45) = 1182 \text{ ml/min}
\]
Measurement of renal blood flow

Substances used for measurement of GFR are not suitable for the measurement of Renal Blood Flow. Why?

Because Inulin clearance only reflects the volume of plasma that is filtered (GFR) and not that remains unfiltered (RBF) and get passes through the kidney.

It is known that only 1/5 of the plasma that enters the kidneys gets filtered. Therefore, other substances to be used with special criteria, so to measure renal blood flow we will have to measure renal plasma flow first and then from the hematocrit we calculate the actual blood flow.

We can’t measure the renal blood flow directly we have to measure the renal plasma flow first.
Filtration fraction

It is the ratio of GFR to renal plasma flow

\[
\text{Filtration Fraction} = \frac{\text{GFR}}{\text{RPF}} = \frac{125}{650} = 0.19
\]

To calculate the filtration fraction, which is the fraction of plasma that filters through the glomerular membrane, one must first know the renal plasma flow (PAH clearance) and the GFR (inulin clearance). If renal plasma flow is 650 ml/min and GFR is 125 ml/min, the filtration fraction (FF) is calculated as

Filtration Fraction = 125/650 = 0.19

0.19 * 100 = 19%
Substances that are completely reabsorbed from the tubules

Example: amino acids, glucose

clearance = zero because the urinary secretion is zero.

Reabsorption rate can be calculated=
Filtration load - excretion rate
= (GFR X P*) - (U* X V)
* The substance needed to be assessed.

Secretion* = (U* X V) - (GFR X P*).
* indicate the substance

Calculation of tubular reabsorption or secretion from renal clearance

Table 19-2 Renal Handling of Solutes

<table>
<thead>
<tr>
<th>For any molecule X that is freely filtered at the glomerulus:</th>
<th>Renal handling of X is:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtration is greater than excretion</td>
<td>Net reabsorption of X</td>
</tr>
<tr>
<td>Excretion is greater than filtration</td>
<td>Net secretion of X</td>
</tr>
<tr>
<td>Filtration and excretion are the same</td>
<td>No net reabsorption or secretion</td>
</tr>
<tr>
<td>Clearance of X is less than inulin clearance</td>
<td>Net reabsorption of X</td>
</tr>
<tr>
<td>Clearance of X is equal to inulin clearance</td>
<td>X is neither reabsorbed nor secreted.</td>
</tr>
<tr>
<td>Clearance of X is greater than inulin clearance</td>
<td>Net secretion of X</td>
</tr>
</tbody>
</table>

Substances highly reabsorbed

Example: Na

it's clearance < 1% of the GFR.

Waste products as urea are poorly reabsorbed

Have relatively high clearance rates.
The glucose clearance is zero at plasma glucose values below the threshold and gradually rises as plasma glucose rises. We can express the excretion of glucose quantitatively at plasma concentrations beyond the threshold, where the glucose reabsorption rate \( T_m \) has reached its maximum.

**Tubular transport maximum for glucose**

**Filtered Load:**
\[
\text{filtered load} = \text{GFR} \times [P]_{\text{glucose}}
\]

**Reabsorption:**

- **plasma [glucose] < 160 mg/dL**
  - filtered load of glucose is completely reabsorbed (no excreted in urine)

- **160 mg/dL < plasma [glucose] < 200 mg/dL**
  - filtered load of glucose is not completely reabsorbed,
  - "threshold," or plasma [glucose] at which glucose is first excreted in urine

- **plasma [glucose] > 350 mg/dL**
  - filtered load of glucose is not completely reabsorbed
  - \( \text{Na}^+ - \text{glucose} \) (SGLT) co transporters are completely saturated
  - maximal glucose reabsorption \( (T_m) = 375 \)

- \( \uparrow \) uptake glucose \( \rightarrow \uparrow \) Filtered rate
- Reabsorption increase with Filtration \( \rightarrow \) glucose is completely reabsorbed
  - if rise plasma glucose level between 160 and 200 \( \rightarrow \) not completely reabsorbed
  - if Continue \( \uparrow \) uptake glucose \( \rightarrow \uparrow \) plasma glucose level to 350 is start excreted in urine and Reabsorption is constant
  - (because the maximal glucose reabsorption from kidney = 375)
100% is filtered and only 50% is reabsorbed
<table>
<thead>
<tr>
<th>Term</th>
<th>Equation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance rate ($C_s$)</td>
<td>$C_s = \frac{U_S \times V}{P_S}$</td>
<td>ml/min</td>
</tr>
<tr>
<td>Glomerular filtration rate (GFR)</td>
<td>$C_{\text{FR}} = \frac{U_{\text{main}} \times V}{P_{\text{main}}}$</td>
<td>None</td>
</tr>
<tr>
<td>Clearance ratio</td>
<td>$\text{Clearance ratio} = \frac{C_s}{C_{\text{main}}}$</td>
<td>None</td>
</tr>
<tr>
<td>Effective renal plasma flow (ERPF)</td>
<td>$\text{ERPF} = \frac{U_{\text{PAH}} \times V}{P_{\text{PAH}}}$</td>
<td>ml/min</td>
</tr>
<tr>
<td>Renal plasma flow (RPF)</td>
<td>$\text{RPF} = \frac{C_{\text{PAH}} \times V}{P_{\text{PAH}}} + \frac{U_{\text{PAH}} \times V}{P_{\text{PAH}}}$</td>
<td>ml/min</td>
</tr>
<tr>
<td>Renal blood flow (RBF)</td>
<td>$\text{RBF} = \frac{\text{RPF}}{1 - \text{Hematocrit}}$</td>
<td>ml/min</td>
</tr>
<tr>
<td>Excretion rate</td>
<td>$\text{Excretion rate} = U_S \times V$</td>
<td>mg/min, mmol/min, or mEq/min</td>
</tr>
<tr>
<td>Reabsorption rate</td>
<td>$\text{Reabsorption rate} = \text{Filtered load} - \text{Excretion rate}$</td>
<td>mg/min, mmol/min, or mEq/min</td>
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$S$, a substance; $U$, urine concentration; $V$, urine flow rate; $P$, plasma concentration; $\text{PAH}$, para-aminobiphenyl; $P_{\text{PAH}}$, renal arterial PAH concentration; $E_{\text{PAH}}$, PAH extraction ratio; $V_{\text{PAH}}$, renal venous PAH concentration.
The formula used to calculate GFR or RPF is \( C_X = \frac{(U_X \times V)}{P_X} \)  
\( X \) could be PAH, creatinine, and inulin.

The formula used to calculate RBF is \( RBF = RPF \div (1 - Hct) \) or \( RBF = RPF\% \div (100 - Hct) \).

We can’t measure the renal blood flow directly; we have to measure the renal plasma flow first.

**Reabsorption rate** = **Filtration rate** - **excretion rate** = \( (GFR \times P^*) - (U^* \times V) \)

**Secretion*** = \( (U^* \times V) - (GFR \times P^*) \).

Substances that are completely reabsorbed (**amino acids, glucose**)
Substances highly reabsorbed (Na)
Waste products as urea are poorly reabsorbed; they

**Glucose clearance**

- **Plasma [glucose] < 160 mg/dL**  
  • filtered load of glucose is completely reabsorbed (no excreted in urine)

- **160 mg/dL < plasma [glucose] < 200 mg/dL**  
  • filtered load of glucose is not completely reabsorbed,

- **Plasma [glucose] > 350 mg/dL**  
  • filtered load of glucose is not completely reabsorbed,  
  • maximal glucose reabsorption (\( T_m \)) = 375
MCQs

1. what is the Renal clearance for creatinine, if
   Concentration of creatinine in urine = 12 ; in the plasma = 7 and urine flow rate = 18 ?
   a. 31  b. 4.6  c. 10.2  d. 44

2. what is the renal plasma flow and renal blood flow for PAH if hematocrit is 50 % , Conc. of PAH in urine =30 mg/ml , in arterial blood = 0.5 mg/ml, Urine flow=3 ml/min,?
   a. 580 – 1000  b. 110 - 400  c. 180 - 360  d. 100 - 500

3. Substances that are completely reabsorbed from the tubules is:
   a. Glucose  b. Na  c. amino acids  d. a and c

4. what is the Reabsorption rate for amino acids if GFR = 1 , Conc. in urine = 0 mg/ml , in arterial blood = 80 mg/ml, Urine flow= 1 ml/min ?
   a. 1  b. 80  c. 0  d. 40

5. maximal glucose reabsorption ($T_m$) =
   a. 350  b. 375  c. 300  d. 200

6. The glucose clearance is
   a. 1  b. 4  c. zero  d. 0.1

7. Substances used for measurement of GFR are suitable for the measurement of Renal Blood Flow
   a. T  b. F

8. We can use the Na to measurement of GFR
   a. T  b. F

Ans. : 1.a , 2.c , 3.d , 4.b , 5.b , 6.c , 7.b , 8.b