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MODELING OF POSSIBLE MOVEMENTS OF A SINGLE HUMAN KIDNEY

Abstract. *The article deals with detection of regularities of possible movements of a single kidney in case of enlargement of its weight after removal of a contralateral one. To investigate the movement of a single kidney with its increasing weight center-of-mass motion theorem was applied. Within the norm the kidney is located in quasi-balance under the effect of forces: kidney weight and equal forces, by means of which the surrounding distributed elastic medium affects the kidney. With increasing kidney weight its center moves in the plane of material symmetry and starts to descend. With increasing kidney weight in case its width, length and thickness of the kidney increase proportionally, the movement of the kidney occurs at the expense of its turning in the plane of material symmetry clockwise.*

Key words: *single kidney, modeling, kidney position.*

Introduction. The problem of a single kidney in urology is a special one as the notion "healthy single kidney" is relative, since "its function is performed on the edge of resources" [4]. Condition of a single kidney (SK) is one of the most topical and least studied issues in modern urology [5]. It is in the condition of hypertrophy, hyperfiltration and other adaptive phenomena [3]. The main danger for a single "healthy" kidney after nephrectomy remains in the possibility of occurring nephrolithiasis depending on the fact whether the kidney was removed regarding nephrolithiasis or other diseases [7]. A high risk of development of nephrolithiasis of a single kidney is evidenced in patients who underwent radical nephrectomy. Patients with a single kidney after nephrectomy are in the risk group since the danger of occurring nephrolithiasis increases [2]. It can be associated with compensatory hypertrophy, structural and physiological changes resulting in formation of stones [1]. Increasing kidney weight often leads to nephroptosis. The position of the kidney is important to be aware of in order to assess the mechanisms of complications development.

Objective: to clarify regularities of possible movements of a single kidney in case of its increasing weight after removal of a contralateral one.

Materials and methods.

While modeling possible movements of the left kidney the following assumptions are accepted:

1. The kidney is considered to be a homogeneous body;
2. The kidney possesses the plane of material symmetry;
3. The kidney surroundings is isotropic and elastic;
4. An average elasticity of K medium where the kidney is located is identical on all the kidney borders;
5. Neglect of shearing stresses (forces) on the kidney borders with environment.

In case of normal (natural) position of the left kidney (Fig. 1) the axis η running through its poles declines to the left and to the vertebral column, and it forms the angle α with the vertical axis Z of the immovable coordinate system X Y Z. The axis ζ of the movable coordinate system is perpendicular to the kidney axis η and directed to the side of kidney convexity and is located in the plane of the kidney material symmetry. Perpendicular to the plane of material symmetry the axis ξ is lined into the side where the turn from the axis ζ to the axis η is seen counterclockwise. Since the kidney is declined to the left at the angle α to the axis Z, the waste product of the kidney (urine) without delay flows from the renal pelvis along the ureter to the urinary bladder. The kidney is in quasi balance under the action of the following forces: kidney weight (P), resultant forces by means of which the external distributed elastic medium affects the kidney from above (F_1), below (F_2), from the side of the renal pelvis (F_3), from the side of the lateral border (F_4), in front (F_5) and from behind (F_6).

To investigate the movement of a single kidney in case of increasing its weight the center-of-mass motion theorem is used [6], when the center of the mechanical system moves as a material point which mass is equal to the mass of the whole system affected by the external force equal to the resultant force of all the external ones influencing upon this system:

$$m \cdot \bar{a}c = \bar{P} + \overline{F_1} + \overline{F_2} + \overline{F_3} + \overline{F_4} + \overline{F_5} + \overline{F_6} \quad (1)$$

where: $m=\frac{P}{g}$ - kidney weight;

$\bar{a}c$ - acceleration of mass center,

g- acceleration of free fall near the surface of the earth.

Since the kidney movement is extremely extended in time the kidney can be examined in quasi-stationary regimen, that is, with $\bar{a}c \cong 0$, when at every moment of time the kidney is in the state of equilibrium:

$$\bar{P} + \overline{F_1} + \overline{F_2} + \overline{F_3} + \overline{F_4} + \overline{F_5} + \overline{F_6} = 0 \quad (2)$$

Results and discussion. Stage 1. In case the kidney weight becomes Δm bigger its mass center dislocates in the plane of material symmetry along the axis η to the value a (Fig. 1). Under the action of force ($\bar{P} + \Delta\bar{P}$) the kidney begins to descend, and if the forces$\overline{F_3}$, $\overline{F_4}$, $\overline{F_5}$, $\overline{F_6}$ do not change their values and directions ($\overline{F_3} = -\overline{F_4}, \overline{F_5} = -\overline{F_6}$), the kidney moves downward along the axis η to the value Δη. Under conditions of the kidney balance after its dislocation from (2) it is found in the projection to the axis Y:

$$K \cdot \Delta\eta \cdot \cos\alpha = \Delta m \cdot g \quad (3)$$

In case the current position of the kidney is retained the fluid from the renal pelvis to the urinary bladder flows freely.

Stage 2. In case of enlargement of the kidney volume (kidney weight) under conditions when its width, length and thickness increase proportionally, that is, the plane of material symmetry is unchanged, the kidney moves at the expense of its turn in the plane of material symmetry clockwise. If at the given moment of time the kidney turns in the plane of material symmetry at the angle$\Delta\beta$, it dislocates down along the axis η on the value.

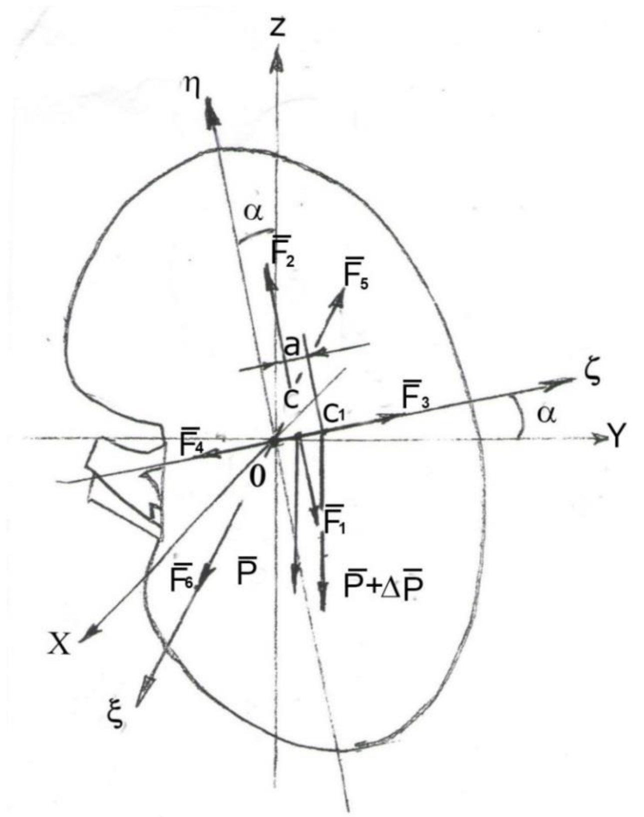

Fig. 1. Normal (natural) position of the left human kidney. Note: X Y Z – immovable Cartesian coordinate system; η ζ ξ – movable orthogonal coordinate system; η Oζ – the plane of the kidney material symmetry; α – gradient angle of the kidney axis to the vertical axis; P – kidney weight; F_1 – force acting on the kidney downward; F_2 – force acting on the kidney upward; F_3 – force acting on the kidney from the side of the renal pelvis; F_4 – force acting on the kidney from the side of the lateral border; F_5 – force acting on the kidney from the front to the back; F_6 – force acting on the kidney from the back to the front; O – reference point of the coordinate system; C – center of the kidney weight; a – dislocation of the mass center from the point C in case of increasing kidney weight.

$$\Delta\eta_2 = a \cdot sin\Delta\beta \quad (4)$$

Therefore, kidney dislocation in case of enlarged kidney weight considering (3) of the stage 1, will be the following:

$$\Delta\eta = \frac{\Delta m \cdot g}{K \cdot cos\alpha} + a \cdot sin\Delta\beta \quad (5)$$

Boundary dislocation of the kidney occurs when the axes Z and η will be in the vertical plane, that is, the angle in the kidney frontal plane is reduced to zero. In this kidney position the fluid from the renal pelvis still flows freely. The external medium below the kidney will be compact together with changes of its mechanical characteristics (elasticity, elasticity module).

Stage 3. In case of kidney turning, that is, when the angle decreases in the frontal plane, the kidney square below increases under the action of the force $\overline{P_1} = \overline{P} + \Delta\overline{P}$ (Fig. 2). The kidney will not descend, it will turn clockwise, and the angle α in the frontal plane will be of a negative value.

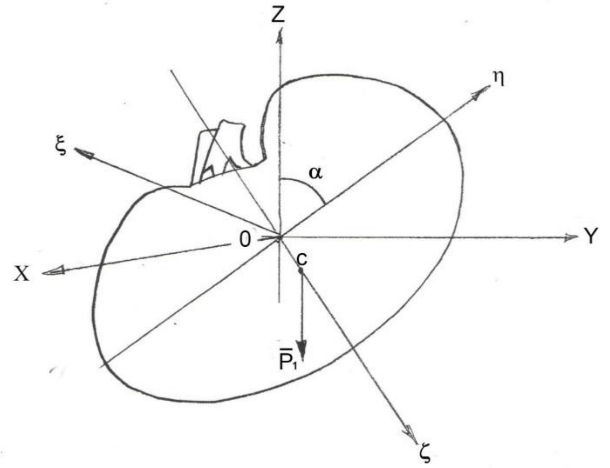

Fig. 2 Position of the kidney with a negative angle in the frontal plane. Note: see symbols Fig. 1.

The angle value of the kidney turning depends on the character of its weight increase and elasticity of the medium from the left and right sides of the kidney. In case the kidney weight in the upper part (higher the plane ξO ζ) increases quicker than in the lower part of the kidney, the kidney turning clockwise round the axis O X can occur more intensively in time as compared to the process of a gradual increase of the kidney volume.

In case of the negative angle α in the frontal projection of the kidney (Fig. 2) the flow of the fluid from the renal pelvis becomes more difficult. Urine is collected in the renal pelvis, and urine in the kidney is constantly stagnated. First of all, this process increases its weight, and the second, a part of urine does not flow from the kidney freely resulting in the formation of sediment (sand, stones) in the kidney. In addition, the intensity of blood flow in the renal vessels decreases.

Conclusions. 1. Increase of the kidney weight results in its dislocation downward along the kidney axis and decrease of the angle in the frontal plane of the kidney, and physical properties of the medium where the kidney is located change as well.

2. In case of zero value of the angle in the frontal kidney projection (boundary position) the process of urine stagnation in the renal pelvis are absent.

3. In case the kidney axis turns clockwise from the vertical axis Z, urine does not flow from the kidney freely and its part is constantly retained in the renal pelvis, which has a negative impact on its function, increases its weight considerably, resulting in the formation of sediment including that one in the form of solid deposits.

Prospects of further studies. The stages in case of increasing angle of rotation, especially those close to critical ones, require further investigation. At the same time, special attention should be paid to a considerable nonlinearity of characteristics and position of the local additional masses.

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