NUMERICAL SIMULATION OF FLOW IN ANASTOMOTIC COMPLEX AFTER GASTRIC RESECTION WITH GASTROJEJUNAL ANASTOMOSIS

O. Vaida[1], L. Vaida[2], A. Andercou[3].

[1] Department of General Surgery, Municipal Hospital Dej, Romania
[2] Department of Mechanical Engineering of the Faculty of Mechanical Engineering of the Technical University of Cluj-Napoca
[3] University of Medicine and Pharmacy „Iuliu Hatieganu", II Surgical Clinic, Cluj-Napoca, Romania

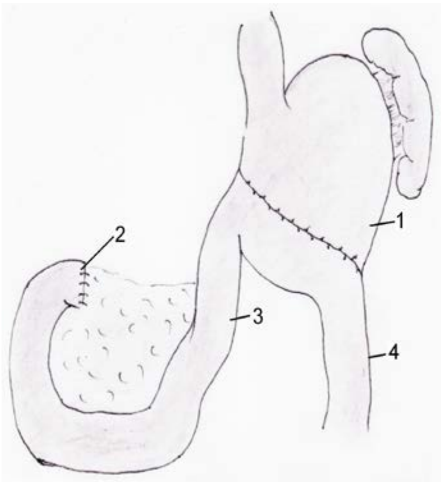
Abstract
Aim: To investigate the flow by numerical simulation in mechanical hydraulic models that approximates the stomach and gastric resection procedures Billroth I (BI) and Billroth II (BII).
Method: Are used geometries axially symmetric non-deformable. Calculations obtain hydrodinamic sizes for all configurations of interest: normal geometry and geometries that simulate gastric resection procedures BI and BII.
Results: By calculating the modulus of resistance, M and of time of emptying it has been found an acceptable flow for procedures BI (Péan), Y Roux (Y-R) and gastric resection Leger (GRL). In techniques BII, Reichel-Polya (R-P), Hoffmeister-Finsterer (H-F) the flow is far away from that of the normal geometry.
Conclusions: Operations drastically alter the flow in accordance with the extent of anatomical changes.

Keywords: Numerical simulation, Gastric resection, Anastomosis.

Introduction

Motor function of the stomach and small intestine is essential for digestion of food. It is met of smooth muscles of these digestive segments with the participation of intramural nerve plexus Meissner and Auerbach. Stomach muscles are divided into three layers: external, longitudinal, middle, circular and internal with oblique fibers. The intestine has one external muscular layer and another internal circular.
Gastric and intestinal smooth muscle contraction is coordinated by a complex nervous and endocrine mechanism that controls integrated and other functions: secretory of digestion and absorption.
Stomach motor function is initiated by smooth muscle cells, by the contraction what triggers „migratory motor complex" (MMC). This is carried out in four phases and repeat cyclically to 90 minutes, producing peristaltic waves (1).
,,Flow" to the stomach is materialized by the their sequence and has the following consequences: gastric filling, fragmentation and mixing foods with gastric juice and finally discharge of chim into the duodenum through the pyloric sphincter.
Pyloric sphincter along with the lower esophageal sphincter are specialized formations who acts synergistically in regulating ,,impulses and outputs" from the stomach.
Pyloric sphincter by adjusting his tonus, opposes of discharge into the duodenum to remaining unprocessed food particles in the stomach and stops duodenogastric reflux (2).
To explore the digestive segments have at hand various parameters like: intraluminal pressure, time and velocity of the exhaust, resistance to flowing, etc.
There are numerous studies that can investigate anatomically intact gastrointestinal tract, but there are few those explore the digestive tract after surgery.
In these cases impediments of explore are due to anatomical changes achieved trough operation on the one hand and on the other through the difficulties to find appropriate method of investigation whose results reflect with accuracy the functionality.
Known two main types of digestive reconstruction after gastrectomy: Billroth I (BI) with gastro-duodenal anastomosis and Billroth II (BII) with gastro-jejunal anastomosis.

Depending on the type of intestinal section for manufacturing anastomosis, processes BII can be: BII by longitudinal enterotomie (LE) and BII by transverse enterotomie (TE).
The procedures BII most used are: Reichel-Polya (R-P) Hoffmeister-Finsterer (H-F) through LE and the fitting in Y à la Roux (Y-R) (fig.1).



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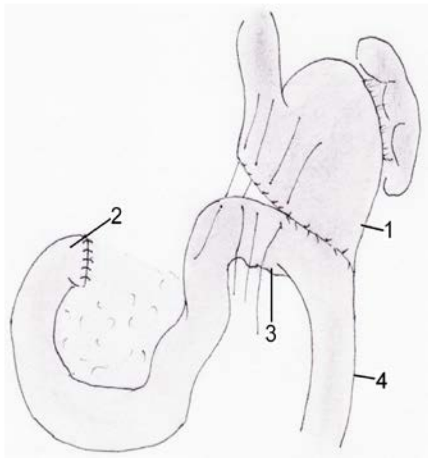
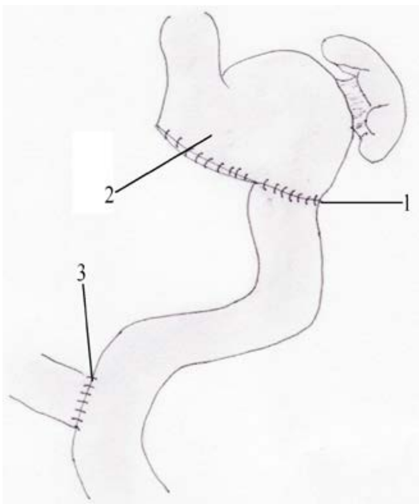


B.

Fig. 1. Procedures BII through LE

A. Reichel-Polya. B. Hoffmeister-Finsterer . 1 - gastric stump; 2- duodenal stump; 3 - afferent loop; 4- efferent loop.

The method through TE was launched in 1950 by L. Leger gastric resection Leger (GRL) (fig 2).



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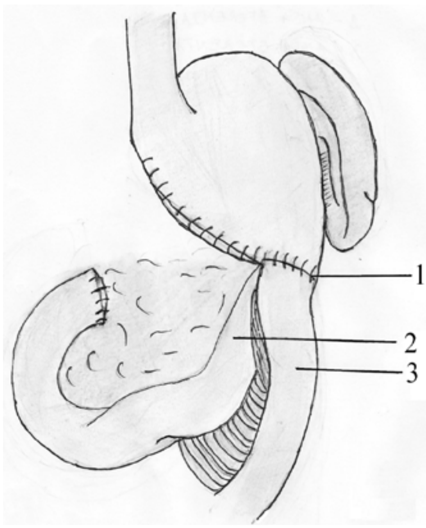


B.

Fig. 2. The fitting Y-R and GRL throughTE

A. The fitting Y Roux: 1- gastro-jejunal anastomosis; 2- gastric stump; 3- jejuno-jejunal anastomosis

B. Gastric resection Leger: 1- gastrojejunal anastomosis; 2-afferent loop; 3- efferent loop.

In terms of peristalsis the BII anastomosis are *isoperistaltic* when the stomach and jejunum have the same peristalsis direction and *antiperistaltic* when the stomach and afferent loop have the opposite direction of peristalsis (3).
Through gastro-jejunal anastomosis is born gastro-jejunal anastomotic complex (AC). AC is a structure resulting by uniting of anastomotic partners responsible by postoperative disordes. AC is different in procedures BII especially according on the type of enterotomy used, LE or TE.
Whatever type of enterotomy in gastrojejunal anastomosis AC has the following components: *afferent loop* (AL), *anastomotic area or moth anastomosis* and *efferent loop* (EL).
After LE anastomotic area is wide, gastric slope being the whole gastric trance (R-P) or half of it (H-F) and intestinal slope is jejunum incised longitudinally on distance corresponding to trance. AL and EL communicate each with anastomotic space, trough two openings, for entry (AL) and output (EL) distant from each other to the small and to the great curvature of the gastric stump.
After TE anastomosis is to the great curvature of the gastric stump, with diameter of 3-4 cm. AL and EL are in continuity and delimited endoluminal of a parietal spur. They have a common opening toward the gastric anastomotic slope. Gastrojejunal anastomosis by ET resembles with one end-to-end.
Numerical simulation can explore the functionality of AC but has limits related rigidity mechanical-hidraulic models that approximates the stomach and surgical procedures. It is a research stage which can be followed by the development of experimental models or experience on animals if deemed necessary.

Working hypothesis

For numerical simulation of flow are necessary hydraulic mechanical models which reproduce approximately the stomach and anastomotic montages achieved by the techniques of digestive reconstruction after gastrectomy.
Flow from the stomach intact into the intestine is the reference point to assess AC with specific structure for each technique of gastric resection.
Are to be sought the differences of flow which exist between techniques BI and BII and that differ by the type of anastomosis used, gastroduodenal (BI) or gastrojejunal (BII). Is important to mention that in the techniques BII duodenum is excluded from gastro-intestinal circuit, and that the AC architecture is amended depending by type of enterotomy (LE or TE) for anastomosis.

Material and method

Simulation stomach evacuation

From point of view hydrodynamic gastric evacuation can be represented like a non-permanent and multiphase movement which takes place in a complex field, deformable.
The flow is generated by two factors:

- pressure difference between the stomach and duodenum;
- peristaltic movements of the walls of these organs.

Between the stomach and duodenum is located *pyloric sphincter*. He has a smooth circular musculature with annular thickenings, which under physiological conditions works like a unidirectional mechanical valve (fig.3).

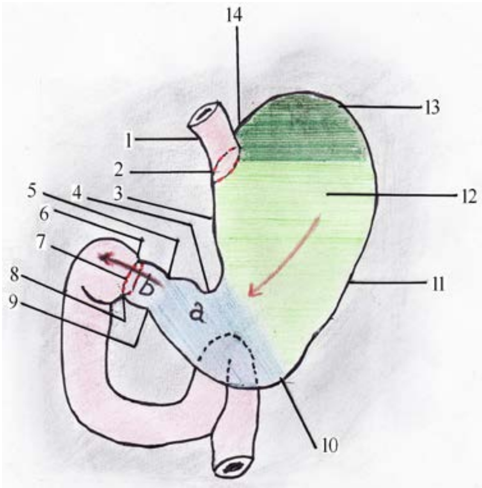


Fig.3.The stomach and duodenum (7-pyloric sphincter; arrows indicate the direction of the outlet of the stomach)

Measurable parameters that have relevance for the hydrodynamic study are:

- the pressure in the stomach: p1
- pressure difference Δp (fig.3)

Δp is the size of dynamic most important which is based mathematical modeling of the flow from the stomach to the duodenum.

Local balance between Δp and elastic tension of pyloric musculature provide its normal operation.

For a normal function manometric relative pressure p_m registered at the opening of pylorus is between 80 - 120 mm H_2O, respectively 784,532 - 1176,78 Pa (1 mmH_2O = 80665 Pa), a value that is induced by the muscle tension of pylorus.

Pressure values outside this range can mean disfunctions of the pylorus.

For the hydrodynamic calculation, pressures values Δp and p_m are the fundamental size without which cannot obtain relevant quantitative results, simulation being limited at a qualitative description of the phenomenon of gastro-duodenal flow.

Was created a first 2 D model that can study gastric emptying and who later allow qualitative assessments about it, in case of surgical procedures that change constructive this model. Proposed model for the analysis of hydrodynamics in gastric emptying uses an axial-symmetric geometry non-deformable (fig.4). *Stomach* is considered a reservoir with variable section, and *duodenum* and *small* intestine, two rigid sections in series, while *large intestine* has the rol of an adjusting tap. The main objective of using this model is to get credible numerical solutions through movement created in a rigid area at the ends of which applies constant differences of pressure. Pylorus is considered a component of local resistance of the segment which simulates duodenum, in direct relation with the size pressure variation between stomach and duodenum (fig.4).

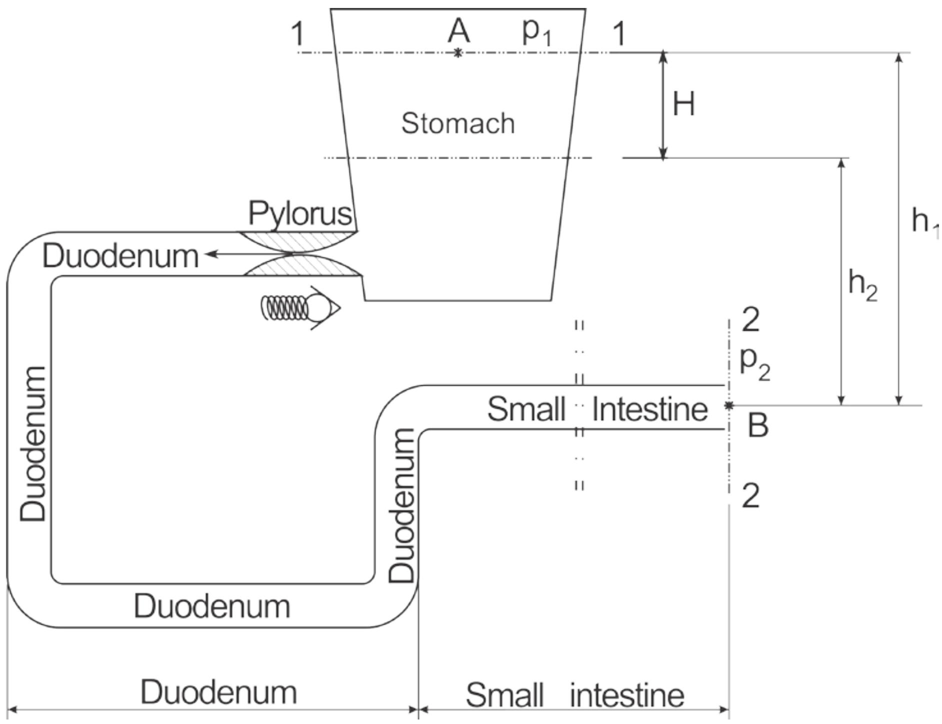


Fig. 4. Geometry used to simulate evacuation stomach

Numerical simulations describe completely, hydrodynamics movements analyzed for a Newtonian fluid (water). Calculations allow obtaining of hydrodynamic size, for all configurations of interest: normal geometry and the geometries that approximates gastric resections procedures. BI (Péan) and BII (R-P, H-F, Y-R, GRL). The analysis will be made for low Reynolds numbers of the movement because the evacuation of the stomach is a very slow process.
It will analyze the escape of liquid for a given model aiming to determine the *time of emptying*, in which the level of water in gastric reservoir, reaches from baseline h_1 at one final h_2 where $h_2 < h_1$ (4, 6)
Such analysis starts from the fact that the movement cannot be considered *permanent* because hydraulic parameters change in time. For solving, the movement is considered as a succession of permanent movements, that take place at *time intervals elementary*, and total time will be obtained by summing the *elementary time.*
It is considered the general case of a reservoir which empties free through a pipe, whose hydraulic resistance module is M. It is to be determined separately at all the variants analyzed (fig.4).
Flow is clearly made from reservoir toward evacuation. By choosing of a the reference plan in accordance with figure 4 gives:

$$\frac{p_1}{\rho \cdot g} + h_1 \rangle \frac{p_2}{\rho \cdot g} + h_2 \tag{1}$$

Will fallow the time in which, free surface in the reservoir reaches from the value h_1 at h_2. The Energy Law (Bernoulli's equation) between points A and B where occurs movement it can be written in accordance with the relationship from Figure 4 as follows:

$$\left(\frac{p_1}{\rho \cdot g} + h_1\right) - \left(\frac{p_2}{\rho \cdot g} + h_2\right) = \left(M - \frac{\alpha}{2g} \cdot \frac{1}{A_1^2(h)}\right) \cdot Q^2 \tag{2}$$

Or:

$$\frac{\Delta p}{\rho \cdot g} + H = M^*(h) \cdot Q^2 \tag{3}$$

Where: $\Delta p = (p_1 - p_2)$ is the static pressure difference between points A and B;

$H = h_1 - h_2$ = is the height of position between points A and B;
$M^*(h)$ = is the global module of hydraulic resistance which includes and the kinetic terms;
Q = the exhaust flow

Because h_2 is constant in the case of elementary variation can write:

$$dh_1 = dh \tag{4}$$

Taking account of the continuity ecuation (mass conservation law) results:

$$Q \cdot dt = -A_1(h) \cdot dh \tag{5}$$

Elementary time variation is:

$$dt = -\frac{A_1(h) \cdot dh}{Q} \tag{6}$$

If gon replace in the relation 6 flow expression (Q) resulting of 3 is obtained:

$$dt = \frac{A_1(h) \cdot \sqrt{M^*(h)}}{\sqrt{\frac{\Delta p}{\rho \cdot g} + h}} \cdot dh \tag{7}$$

By the integration result *of the reservoir depletion time T* between the initial difference H (existing at the moment t=0) and final difference (at the moment t=T):

$$T = \int_0^H \frac{A_1(h) \cdot \sqrt{M^*(h)}}{\sqrt{\frac{\Delta p}{\rho \cdot g} + h}} \cdot dh \tag{8}$$

For explaining overall module of resistance will apply energy law, between sections 1-1 and 2-2 of the considered system. Under this law one can write:

$$\frac{\alpha_1 \cdot v_1^2}{2 \cdot g} + \frac{p_1}{\rho \cdot g} + h_1 = \frac{\alpha_2 \cdot v_2^2}{2 \cdot g} + \frac{p_2}{\rho \cdot g} + h_2 + h_{p_{1-2}} \tag{9}$$

Where: - α_1 si α_2 are coefficients by nonuniformity of speed (Coriolis coefficient). These coefficients take into account uneven distribution of speed in the normal section studied. For these coefficients will be adopted the value $\alpha_1 = \alpha_2 = 2$, appropriate of laminar flow in ducts with circular section:

- the terms $\frac{\alpha \cdot v^2}{2 \cdot g}$, represents the kinetic energy reported at weight
- the terms $\frac{p}{\rho \cdot g} + h$ represents the potential energy reported at weight
- $h_{p_{1-2}}$ represents loos of *total hydraulic load* between sections 1-1 and 2-2. To note that these are dissipation of energy that can be found in the form of temperature increases in the fluid the moving.

Means that loss of *total hydraulic load* is the ratio of the flux of mechanical energy dissipated between the two sections of the a current of fluids and the product ρgQ where p is density of the fluid, g is gravitational acceleration and Q is the volume flow.

The loss of total hydraulic load $h_{p_{1-2}}$ is determined by summing losses of load uniformly distributed, h_l and of locale losses $h_{loc.}$ For a circular pipe of diameter *d* and length *l* along which there is a number *n* of irregularities (disturbing elements like: narrowing or widening of the section, elbows, bends etc.) the loss of hydraulic load it write:

$$h_{p_{1-2}} = h_l + \sum_{i=1}^{n} h_{loc_i} \tag{10}$$

Taking account of relationships for loss uniformly distributed and for local losses which is expressed by the relations:

$$h_l = \lambda \cdot \frac{l}{d} \cdot \frac{v^2}{2 \cdot g} \text{ and } h_{loc} = \varsigma \frac{v^2}{2 \cdot g} \tag{11}$$

where : λ is coefficient of the linear loss distributed;
l – the length of pipe;
d – diameter of the pipe;
v – fluid velocity in the pipe;
ζ – coefficient of local loss;

and also the equation of continuity:

$$Q = v \cdot A \tag{12}$$

Is obtained for value of miscarriages, expression

$$h_{p_{1-2}} = \left(\lambda \cdot \frac{l}{d} + \sum_{i=1}^{n} \varsigma_i \right) \cdot \frac{Q^2}{2 \cdot g \cdot A_1^2} \quad , \tag{13}$$

and for value of resistance modulus

$$M = \left(\lambda \cdot \frac{l}{d} + \sum_{i=1}^{n} \varsigma_i \right) \cdot \frac{1}{2 \cdot g \cdot A_1^2} \tag{14}$$

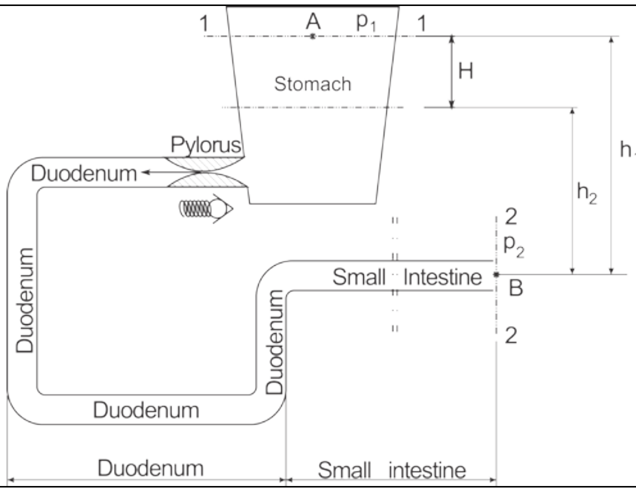
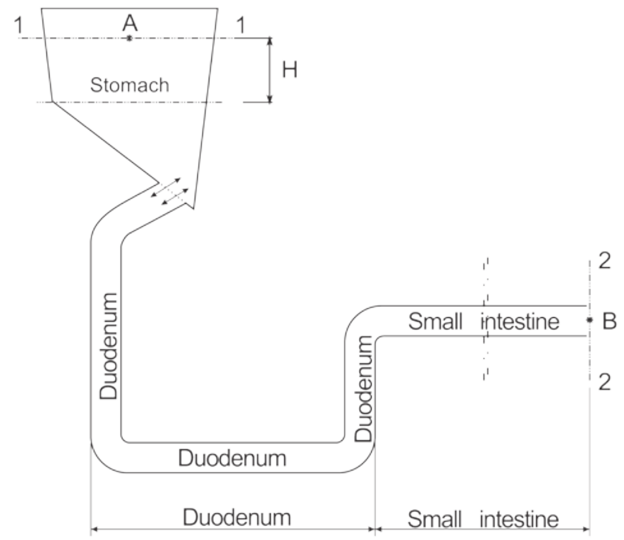
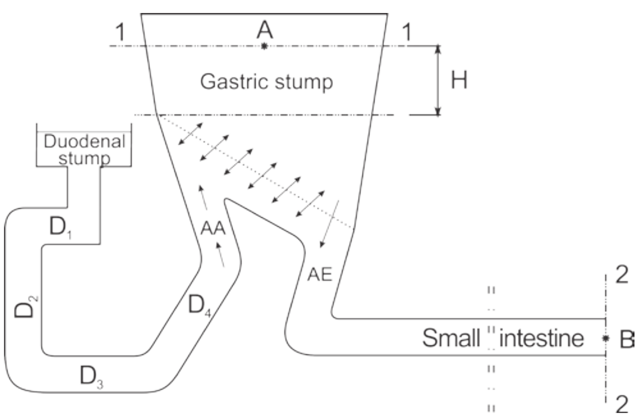
Medical literature contains numerous dates about gastric resection, but in the majority of cases, the studies are limited at quantifying of the extirpations, and efficiency of the operation of extirpation. The main parameter that take it in consideration is the pressure drop in the area of intervention.
For shaping stomach evacuation is necessary following average values of physical sizes which influencing it:

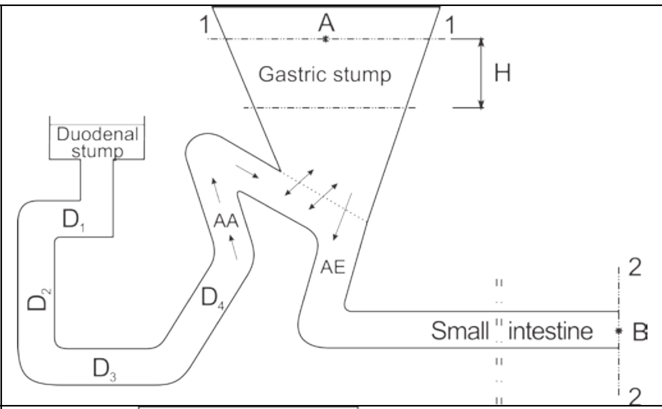
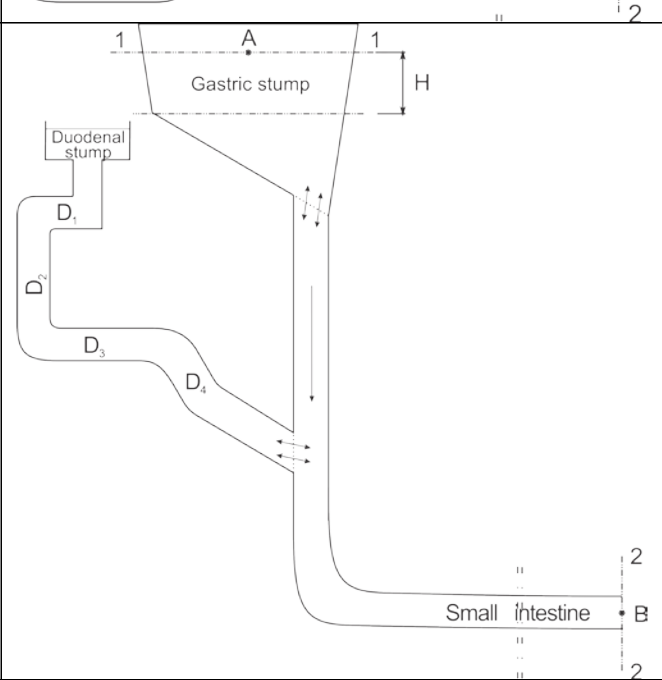
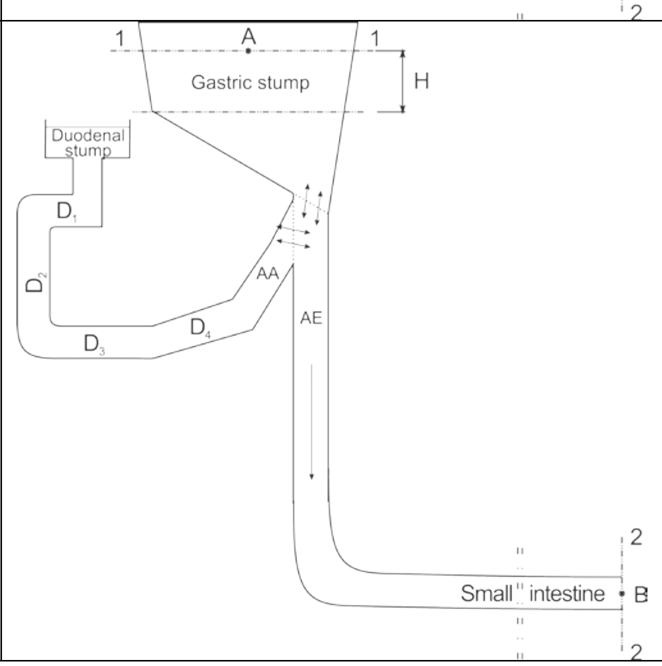
- the exhaust flow Q = $8{,}83 \cdot 10^{-6}$ m^3/s;
- the normal capacity of the stomach V_0 = $1{,}2 \cdot 10^{-3}$ m^3;
- the average diameter of the duodenum $d_d = 3 \cdot 10^{-2}$ m;
- the average diameter of small intestine $d_s = 3 \cdot 10^{-2}$ m;
- the density of fluid chyme ρ = 1000 kg/m^3;
- dynamic viscosity of fluid chyme η $\approx$4 mPa$\cdot$s;
- the average speed v = $\frac{4Q}{\pi \cdot d^2} \approx$0.0125 m/s, which corresponds to a Reynolds number of about 120;
- stomach pressure $p_1 = (0{,}7 \div 1) \cdot 10^3$ Pa.

Results

In the case of gastric resection shall be amended the conditions of flow downstream of the stomach. They influence *resistance modulus* **M**. In table 1 are presented his values, calculated for each type of gastric resection. Also are measured *the emptying time* **t** in all anastomotic montages for a volume equivalent to 1/3 of the volume of the stomach (gastric stump volume remaining after resection).

Table 1

Type of gastric resection	*The main scheme equivalent*	*Modulus of resistance [s^2/m^5]*	*Time emptying [s]*
Stomach in normal operation		*$2.83 \cdot 10^9$*	*28.7*
Gastric resection Péan		*$1.9 \cdot 10^7$*	*2.35*
Gastric resection Reichel-Polya		*$1.1 \cdot 10^7$*	*1.72*

Gastric resection Hoffmeister-Finsterer		*$1.2*10^7$*	*1.8*
The fitting Y Roux		*$1.7*10^7$*	*2.23*
Gastric resection Leger		*$2.71*10^7$*	*2.81*

Discussion

After gastrectomy digestive reconstruction with gastrojejunal anastomosis (GJA) gives rise at anastomotic complex (AC). He is the new section digestive of flow resulted through surgical act, which changes substantially the area.

The flow in AC can be explored by calculating the modulus of resistance M, a value that shall be amended, depending on the elements of local and linear geometry, with significance for energy loss at the fluid passing through the system (4).

Towards normal anatomical configuration interfere local and linear resistance factors, that influence modulus M at all procedures of gastrectomy used. Here are few details that affect the flow in the system: suppression of pyloric sphincter, the exclusion from circuit of the duodenum; length of the afferent loop (AL): izo- or antiperistaltic montage; intestinal section type (longitudinal or transverse). Other factors of resistance may be: parietal spur, anastomotic loop bends, imposed by technique or accidental; the multitude layers of digestive suture; deficiencies by fixation of anastomosis at mesocolic breach; adherence syndrome postoperatively that can deform AC.

Watching results from table 1 shows the most acceptable flowing in gastric resection BI (Péan), in technique on loop in Y Roux (Y-R) and after gastric resection Leger (GRL). In the procedures BI and Y-R, anastomosis of gastric stump with duodenum or jejunum is done end-to-end. In GRL although it is a suture gastrojejunal end-to-side due to cross-enterotomy behave as one end-to-end. Over time termino-terminal anastomoses can arrive sphincters comparable with the pylorus (5).

The farthest flowing from normal anatomy is observed after techniques BII (R-P) and (H-F). Local resistance elements from these techniques, reflected by modulus M and the time of emptying are: long AL; hipofunctional segment between AL and EL, obliquity of mouth anastomosis; longitudinal section of the jejunal wall (interruption circular muscular fibers), sutures in two plans, antiperistaltic gastrojejunal montage etc.

Conclusions

The surgical intervention alters substantially the flow regardless of the process used after gastrectomy by changing the local resistances.

The flow is acceptable after techniques that change as little the digestive tract (section flow) and doesn't affect its structure.

Deficient flow regime even if the simulation was done on models with rigid walls, it may reflected the postoperative disorders.

References

1. Gheorghe C. – Fiziologia gastrică din Tratat de chirurgie vol.VIII, Partea I B - Chirurgie Generală sub red. Popescu I. – Editura Academiei Române – Bucureşti 2008; 1299-1301.
2. Hăulică I. Fiziologie Umană- ediţia a III-a Editura Medicală, Bucureşti 2009; 484-94.
3. Filopovic N, Cvetkovic A, Isailovic V, Matovic Z, Rosic M, Kojic M. – Computer simulation of flow and mixing at the duodenal stump after gastric resection – World J. Gastroenterol, 2009 Apr. 28; 15(160: 1990-8.
4. Opruţa D, Vaida L. – Dinamica fluidelor – Editura Mediamira, Cluj-Napoca 2004; 161-170.
5. Popovici Z, Borcean Gh. – Rezecţia gastrică tip Leger reprezintă oare un progres? Revista Română de Chirurgie nr. 2, martie-aprilie 1986.
6. . Idelcic I. I., Indrumător pentru calculul rezistenţelor hidraulice, Ed. Tehnică, Bucureşti, 1984