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ENERGETIC CONSIDERATION ON MICTURITION

Hypothesis / aims of study

In healthy patients, the hydrostatic pressure alone exerted by urine in the bladder is not sufficient to open sphincters and to overcome the pressure of urethral closure. In order to reach a pressure of 12 cm H_20 at bladder neck level it is necessary for the bladder to retain 904 ml. Assuming the absence of obstacle to urine release and that the urethral pressure profile has no closure pressure throughout so that only gravity is acting upon the flow, the model of the emptying corresponds to the formulae of perfect fluids that lack viscosity. According to this hypothesis, the flow going through bladder and urethra can be determined using the principles of energy conservation and those of transformation from potential to kinetic energy. Until emptying in complete, the flow follows this relation:

1) $Q=\sigma\ (2gh)^{0.5}$, where Q is the flow, σ is the area of external urethral opening, h is the height differential between the urine surface in the bladder and the gravitational center of the external urethral opening, and g is gravity acceleration. However, urine liquid is not perfect and it is necessary to evaluate the dissipation of energy due to friction within urine and against the wall, and the dissipation of energy due to widening and narrowing of the pathway. Moreover, it is necessary to consider that the outflow area is not the geometric, but is a fraction of it because of the natural phenomenon of vein narrowing at the outlet. The influence of these factors on the flow can be summarized with the outlet coefficient μ which in hydraulics, when considering rigid tubes and a constant section, takes on an experimental value of approximately 0.6. Assuming a h value of 15 cm, in order to obtain a physiological flow of 15 ml/s, the external urethral opening must be 14.5 mm^2, corresponding to an average diameter of 4.3 mm. The outflow rate is therefore 1.0 m/s. It is proven that this type of movement is laminar, because Reynolds number is close to the limit value of 4000. In the absence of detrusor contraction, the energy of urine in the bladder is 0.15 Kgm/kg = 1.47 J/Kg = 1.47 mJ/ml. The energy of urine upon the outlet is $1.0^2/2g$ = 0.05 Kgm/Kg = 0.5 J/kg = 0.5 mJ/ml.

Study design, materials and methods

The micturition pattern mentioned above is too theoretical and absolutely inadequate because in the bladder there is no free surface at atmospheric pressure, the flow cannot be considered to be like that of a perfect liquid, the section surface is not constant, and the roughness of the section varies in space and time. However, the considerations mentioned above are useful for an adequate evaluation of the problem. If we consider the pressure deriving from detrusor contractions and from abdominal pressure, and hypothesizing a permanent and consistent flow, the moving point within urine as it flows from the bladder to the urethral outlet can be represented by the Bernouilli Law:

2) $Z_1+ P_1/\gamma+V_1^2/2g= Z_2+ P_2/\gamma+ V_2^2/2g+R$. This relationship shows consistency in the sum of all three forms of energy which are present in a fluid, i.e. pressure, potential and velocity. The three terms with the X1 refer to the urine inside the bladder, while those with X2 refer to urine beyond the urethral outlet point (contracted section). Moreover: Z_1 - differential in height between the point in the bladder where the probe measured bladder pressure and the horizontal plane that passes through the center of gravity in the contracted section in the atmosphere; P_1 - liquid pressure in the above-mentioned point; γ - specific weight of the liquid; V_{1-2} - velocity of the fluid in the points under consideration; R - loss of energy between the two points under consideration, both concentrated and process, from the bladder to the atmosphere due to friction, viscosity and sectional variations. The three values are expressed in meters so that they represent the energy of a kilo-weight of the liquid than expressed in Kgm. The flow in the vein can be represented with the same relation recognizing that V now represents the average flow rate. The flow can be studied as a laminar flow rather than turbulent. The value of R can be calculated using Navier's law and, therefore, is directly proportional to the flow, i.e. R = kQ. $Z_2=0$ because the section is located on the horizontal reference plane; $P_2/\gamma = 0$ because the point is at atmospheric pressure; $V_1 = 0$ because the velocity of the urine in the bladder is negligible. Therefore, the following can be expressed:

3) $Z_1+ P_1/\gamma = V_2^2/2g+Kq$ This relationship can be rewritten as follows:

4) $P/\gamma= kQ+ V^2/2g-Z$, which indicated that the height of pressure in the urine inside the bladder, the sum of detrusorial and abdominal pressure, corresponds to the energy lost R = kQ in the flow from the bladder to the urethral outlet point corrected with the value of residual energy, kinetic energy, and with positional energy, where the probe was located.

Results

During micturition it is possible to readily establish the energy loss R = kQ and ascertain information on the causes of this finding, such as obstructions, narrowings, spasms, tight or wide curves, urothelium and epitelium conditions, etc. Even more indicative of the energy loss is the determination of the k value, which gives information that are not changed by the amount of flow Q. When calculating the averall energy lost from the fluid, or rather the energy transferred to the fluid during micturition, it is necessary to calculate the sum of the terms in relation 4 by the weight of the fluid being evacuated. This is necessary because these terms can change during micturition, particularly P, Q and V, while Z remains more or less consistent. Of course, if one knows the trends of the single parameters, it is possible to integrate these values as follows:

$\int k\ Q\ d\ (weight) - \int P/\gamma\ d\ (weight) + \int Z\ d\ (weight) - \int (V^2/\ (2\ g))\ d\ (weight)$,

where $\int k\ Q\ d$ (weight) is the energy lost, $\int P/\gamma\ d$ (weight) is the pressure energy evaluated automatically using urodynamic software with the equivalent expression $\int P\ dv$ = Work out. It is to be noted that P expresses detrusor pressure instead of bladder pressure, which is necessary for these calculations. $\int Z\ d$ (weight) is potential energy, and $\int (V^2/\ (2\ g))\ d$ (weight) is difficult to evaluate because V should be ascertained directly and continuously because the section of external urethral opening can change during emptying ($V = Q/\sigma$). However, this term has a minimal influence on the results because for patients undergoing the Pressure Flow Exam V is typically low and is not higher than a few cm/s.

Interpretation of results

The above relations have been applied to a patient undergoing TURP, thus estimating the V and Z values, utilizing the data of the urodynamic pressure flow exam, and the workout, and replacing bladder pressure with detrusor pressure. Prior to the operation, the energy dissipated during the entire process of emptying $\int$ k Q d (weight) was divided by the volume evacuated, thus making 7.7 mJ/ml. After the operation, the resulting value was 4.8 mJ/ml, for a 38% reduction. As expected, the two values differed significantly. However, their interpretation should also evaluate their dependence on the variability of flow. Immediate evaluation of energy dissipation was made before and after the operation in correspondence of the same value of the flow, 10 ml/s, applying the P of the bladder and estimated V and Z. These are the results: before TURP KQ = 5.2 mJ/ml, and therefore K = 0.52 mJ sec/ml$^{2.}$ After TURP KQ = 3.6 mJ/ml, and therefore K = 0.36 mJ sec/ml^2 Considering the approximation due to the estimated V and Z values, the automatic evaluation of K during the micturition can be made into a diagram and could provide interesting information on the degree of obstruction.

Concluding message

This rational method could be an usefull tool for detecting the degree of obstruction of low urinary tract independently from the value of the flow and also at every istant of the micturition.

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