Urological Research 8, 67-70 (1980)

Urological Research

Momentum Flux Values at Maximum Flow Rate in Normal Males

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Accepted: June 19, 1979

Summary. With the momentum flux apparatus, momentum flux in the voided urinary stream at maximum flow rate was measured in 117 normal males. A normal area of momentum flux related to maximum flow rate has been delineated. The between-person variation of momentum flux was statistically significantly larger than the within-person variation evaluated from repeated voidings from two normal persons. These direct measurements of momentum flux have been compared with those predicted from results obtained with the drop spectrometer. The agreement between the two types of measurements is judged satisfactory.

Key words: Momentum flux - Urinary stream - Urinary drop spectrometer - Normal males.

Momentum Flux Values at Maximum Flow Rate in Normal Males

In a previous paper the construction of the DISA momentum flux apparatus was described and its accuracy for in vitro testing evaluated. An interpretation of measured and calculated parameters has been given (2). The accuracy of this apparatus was found acceptable for the clinical evaluation of meatal properties, and it was stated that simultaneous measurement of momentum flux and flow rate provided information about the distensibility of the meatus during voiding.

This paper reports the momentum flux values obtained at maximum flow rates in healthy male volunteers and compares the results of these direct measurements with those obtained with the drop spectrometer (3). Further the physiological variation in measured results is evaluated on the basis of repeated measurements in two normal persons.

METHOD

The momentum flux apparatus combined with a DISA flow meter was used for these measurements (Fig. 1). A shelf for penis support was not mounted on the apparatus in these voidings, but the apparatus was carefully adjusted in height before each micturition to allow voiding with a horizontal stream.

Each volunteer was instructed to retract the prepuce gently during voiding and to hit the measuring plate horizontally with the stream throughout the voiding. All voidings were performed in privacy.

Results were taken from a six channel hot wire recorder or from an x-y recorder. In addition, a flow curve was taken from a mictiograph.

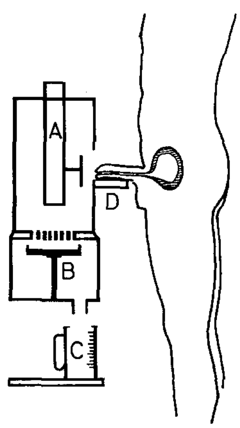

Fig. 1: Schematic drawing of momentum flux meter and flow meter. A-momentum flux transducer. B-flow rate transducer. C-measuring receptacle. D-penis holder

0300-5623/80/0008/0067/$ 01.00

Due to the different and rather large time constants for flux meter and flow meter (0.23 and 0.47 sec respectively), and since most flow curves were almost steady for at least 2 sec at maximum flow rate, only momentum flux at maximum flow rate was used for the evaluation of normal values. These parameters together with age and voided volume were analysed by computer.

For steady flows momentum flux (M) is given by the equation:

$$M = \text{rho} \cdot Q \cdot v \quad \text{(i)},$$

where rho is urine density, Q flow rate and v the average velocity of the stream.

The stream velocity is not constant during voiding (1), and a linear regression of momentum flux plotted against flow rate is not valid. Since

$$Q = v \cdot A \quad \text{(ii)},$$

where A is the stream cross-sectional area, (i) may be rearranged to give:

$$M = \frac{\text{rho}}{A} \cdot Q^2.$$

But the meatus widens and A increases with increasing flow rates (3) so a plot of M against Q could not be a parabola.

Drop spectrometer results have shown a critical flow rate value (Q_c) of 10 ± 2.7 ml/sec (s.e.) in normal males (3) above which the meatus distends with approximately constant stiffness. The momentum flux meter with the present construction is not suitable for dynamic measurements, and only a few observations with maximum flows below 10 ml/sec were obtained. Therefore we cannot at present verify this critical flow rate.

Thus a curvilinear regression of M plotted against Q was undertaken for all measurements with $Q > 10$ ml/sec. Similar curvilinear regressions were performed for the plots from repeated voidings from two normal subjects with 15 and 13 micturitions respectively.

Predictions from Drop Spectrometer Results

For flow rates above Q_c in normal males A increases in such a way that, to a good approximation,

$$A = K \cdot v^2 \quad \text{(iii)}.$$

The constant K is related to the stiffness (i.e. resistance to distension) of the meatus. In normal males

$$K = (1.1 \pm 0.2) \cdot 10^{-6} \cdot \sec^2 \quad \text{(s.e.)}.$$

From (iii) and (ii) we have for $Q > Q_c$:

$$Q = K \cdot V^3.$$

Therefore with equation (i)

$$M = \text{rho} \cdot \frac{Q^{4/3}}{K^{1/3}}, \text{ or}$$

$$M = 0.097 \cdot Q^{1.33} \quad \text{(iiii)}$$

(iiii) is the prediction from drop spectrometer results for M plotted against Q (3).

MATERIAL

117 healthy male volunteers without a history of disease of the lower urinary tract constitute the normal material. 56 young men were soldiers in the Royal Danish Army. The rest were members of the medical staff and factory workers. Only one voiding from each person was used in the study.

Median age was 22 years, 1st and 3rd quartiles 20 and 42.5 years and range 17 to 76 years.

Volumes voided had a median value of 250 ml, 1st and 3rd quartiles 145 ml and 360 ml and range 53 to 710 ml.

RESULTS

In the three age groups (17 - 39, 40 - 59, 60 - 76 years) all volunteers were ranked according to maximum flow rates. Since the distensibility of the meatus might alter with age, persons aged 60 years or more were matched with persons below the age of 40 years - in the order ranked - if flow rates were similar within 1 ml/sec (Table 1). A Wilcoxon matched pairs signed rank test for momentum flux values in the two age groups showed no statistically significant difference, $P > 0.1$. Then momentum flux values plotted against flow rate were analysed disregarding the age - Figure 2.

Table 1. Momentum flux values for persons above the age of 60 years and below the age of 40 years with similar flow rates

Below 40 years		Above 60 years	
M	Q	M	Q
1.2	10.0	2.1	10.0
1.4	11.1	1.4	10.7
1.5	11.2	1.8	11.0
2.2	12.0	1.8	11.5
1.8	12.6	2.0	12.0
2.4	15.0	2.5	15.4
3.8	17.0	2.9	17.5
4.7	19.5	5.0	19.5
4.6	23.0	3.8	22.8
6.4	28.0	6.7	28.0

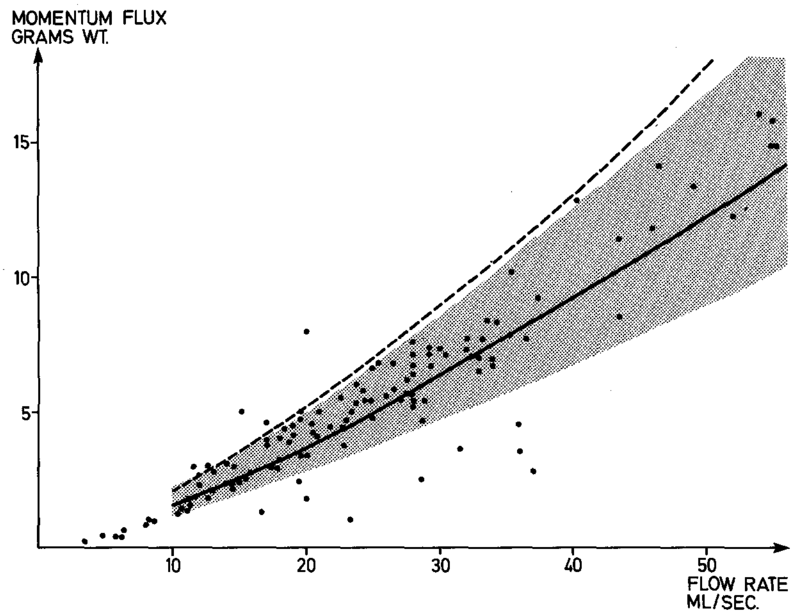

Fig. 2: Momentum flux plotted against flow rate. The thick line is the curvilinear regression. Dotted area is line of regression ± one standard deviation. The dot-and-dashed line is the predicted relation from drop spectrometer results

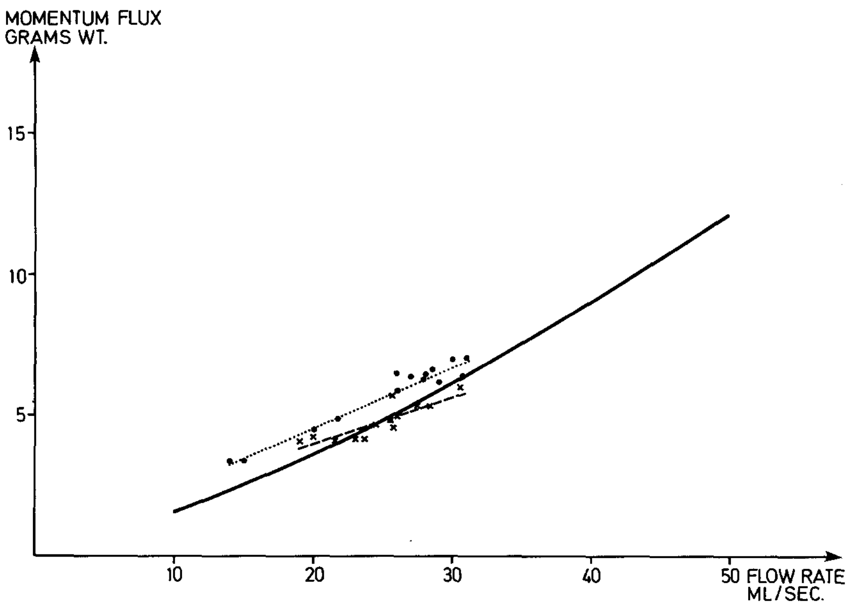

Fig. 3. ...... and ------ are curvilinear regressions for repeated voidings from two normals ($M = 0.271 \cdot Q^{0.94}$ and $M = 0.332 \cdot Q^{0.83}$ respectively). The thick line is the curvilinear regression for all normal males

The curvilinear regression of the plots was:

$$M = 0.082\ Q^{1.28}.$$

The coefficient of correlation was 0.87, $P < 0.001$. The average standard deviation of the momentum flux values from the line of regression was 1.41 grams wt. The predicted relation based on drop spectrometer results is also shown in Figure 2.

Repeated voidings from two normal persons are shown in Figure 3. Standard deviations from the lines of regressions were 0.36 and 0.37 grams wt. respectively. An F-test showed a statistically significant larger variation between persons than within the same person, $P < 0.01$.

DISCUSSION

The variation shown in repeated voidings might be due to physiological as well as instrumental factors. The instrumental contribution has previously been evaluated for steady flows with a standard deviation of ± 0.26 grams wt. Obviously the physiological variation is responsible for part of the standard deviations found for two normals (0.36 and 0.37 grams wt.). These voidings were performed with a shelf for penis support to facilitate a horizontal stream exit angle.

The between person variation was significally larger - 1.41 grams wt. - than the within person variation. All these voidings were undertaken without penis support, and a possible deviation of stream exit angle from the horizontal position might explain some of the variation. Further a few persons perhaps did not retract the prepuce during voiding - although instructed to do so - resulting in a relative low momentum flux value for the flow rate. If some flow curves failed to be almost steady for about 2 sec, error due to the time constants will be important. These direct clinical measurements appear to be consistent with the predictions from the drop spectrometer, except for a correction factor of about 1.4. Deviations from a horizontal stream exit angle could partly be responsible for the relatively lower momentum flux values measured in this study, since deviation in as well upward as downward direction would lower the force of impact on the measuring plate. On the other hand, this relatively small discrepancy may stem from the indirect nature of the drop spectrometer measurements and the assumptions that have to be made in interpreting them. Thus the agreement between the two types of measurement is satisfactory.

The normal area of momentum flux related to flow rate as delineated in Figure 2 facilitates an evaluation of the distensibility of the meatal part of urethra in male patients. In patients with a tight meatus (e.g. organic meatal stenosis) a high momentum flux value (relative to flow rate) should be expected. This method of investigation may be undertaken as a non-invasive screening procedure or as part of a pressure-flow study, and will indicate when an infravesical obstruction is located in the distal part of the urethra.

Acknowledgements. Danish medical research council grant nr: 512-8916 has supported this study.

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