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# Accuracy and Interpretation of Results from the DISA Momentum Flux Meter

H. H. Meyhoff[1], D. J. Griffiths[2], J. Nordling[1] and T. Hald

[1]Department of Urology, Herlev Hospital, University of Copenhagen, Denmark and

[2]Department of Physics, University of Exeter, Devon, England

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Summary. The momentum flux apparatus was tested for accuracy in vitro. Errors were within an acceptable range for clinical evaluation and research of meatal properties in male patients - provided the stream exit angle was horizontal within 10-15 degrees. Measurements from the apparatus give information about the rigid nozzle or distensible meatus from which the stream is discharged. It is stressed, that great caution has to be exercised in the interpretation of the residual kinetic energy density and of the energy loss during micturition.

Key words: Urinary stream, Momentum flux, Accuracy, Residual kinetic energy density, Energy loss.

Measurement of flow rate is a useful urodynamic investigation, well accepted and widely practised. Further information has been extracted from the urinary stream e. g. velocity calculated from the cast distance (8) or from the trajectory on cinefilms (2, 6). The meatal diameter during voiding has been measured on X-ray pictures (4). The force in the urinary stream has been measured by different "dynamometers" (1, 3, 10). A lot of information has been extracted with the Urinary Drop Spectrometer (11).

None of these techniques is in routine use outside a few centres, and a simple and reliable apparatus for the combined measurement of flow rate and force in the voided urinary stream could be of value.

DISA has constructed an apparatus called a "Momentum flux meter". Preliminary clinical results from the testing of this apparatus have been presented earlier (7). The aim of this paper was to evaluate the accuracy of this apparatus and to offer an interpretation of the results.

## MATERIAL

The momentum flux meter consists of a vertically mounted smooth measuring plate connected to two semiconductor strain gauges. It is designed in such a way that the point of force impact on the plate is unimportant. Measuring range is 0-0.2 Newton with a sensitivity of 25 volt/Newton. The transducer's natural frequency is 21 Hertz and its time constant 0.23 sec.

The apparatus is mounted on top of a rotating disc flowmeter (type 14 F 41, time constant 0.47 sec.) allowing simultaneous recording of momentum flux and flow rate - Fig. 1. With the present construction the apparatus can only be used in

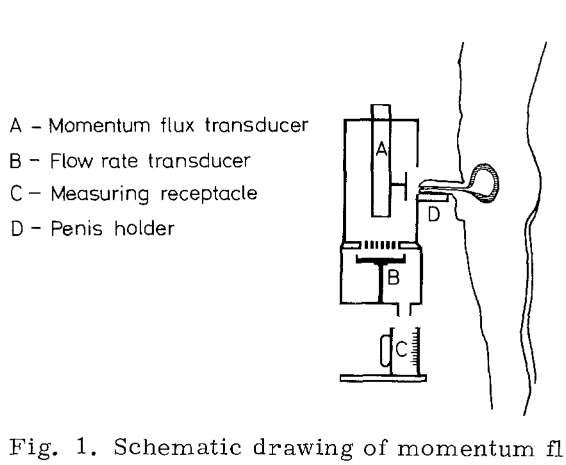


Fig. 1. Schematic drawing of momentum flux meter and flow meter

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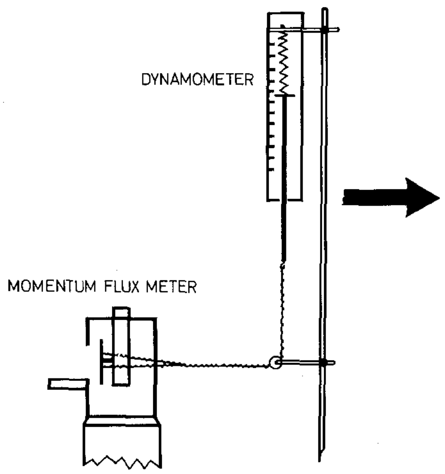


Fig. 2. Test of the momentum flux meter with a dynamometer

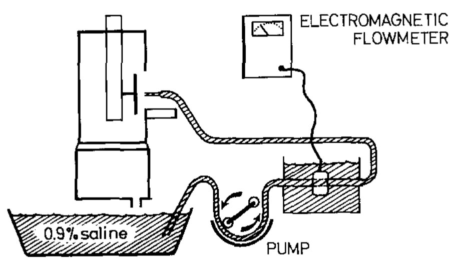


Fig. 3. Test of the momentum flux meter with steady flows from a rigid nozzle

males. In the standing position the patient guides his stream horizontally onto the plate. The penis rests softly on a shelf and the prepuce is gently retracted during voiding.

The momentum flux meter measures the force exerted by the urinary stream on the plate. The force is equal to the momentum delivered to the plate (and there destroyed) per second - called the momentum flux.

Assuming that there is no splash back from the disc and that the flow is constant the momentum flux M is given by

$$M = \text{rho} \cdot Q \cdot v$$

where rho is the urine density, Q is the flow rate and v is the average velocity of the stream. By measuring M and Q simultaneously the velocity of the stream and its cross-sectional area A (= Q/v) can be calculated. So can the residual kinetic energy density Estr in the stream

$$\text{Estr} = 1/2 \cdot \text{rho} \cdot v^2$$

## METHOD

Since a time delay of approximately 0.3 sec exists from the moment the urine hits the momentum flux measuring plate until it reaches the rotating flow rate disc, and because of differences in time constants, only static tests were undertaken.

The momentum flux apparatus was tested with a dynamometer with a measuring range 0-0.2 Newton, accurately calibrated by precision test weights of 1.00 grams, 3.00 grams and 10.00 grams. The measuring plate was pulled from behind by means of a copper wire (diameter $5 \cdot 10^{-2}$ mm) running to the dynamometer over a specially designed glass pulley (friction error ± 2%) - Figure 2.

Further the apparatus was tested in vitro with various steady flows of 0.9% saline. The flow rates were recorded from an electromagnetic flowmeter (Statham SP 2202). A rigid flow probe (inner diameter 5 mm) was used - Figure 3.

Finally the cast distance was compared to measured momentum flux and flow rate values.

Results were recorded on a hot-wire chart recorder, type: Hewlett Packard 7700; calibration: Momentum flux: 2 g.wt/cm, flow rate: 10 ml/cm. (N.B. 1 g.wt = 9.8 Newton).

## RESULTS

Results from the dynamometer calibration are given in Figure 4. Standard deviation and range of error denote deviation of measured values from the line y = x. Figures 5, 6 and 7 give results from tests with the electromagnetic flowmeter.

The nozzle tip was horizontally positioned at a distance of 3 cm from the measuring plate. The impact on the measuring plate was central in all these tests.

Testing with different impact locations on the plate (north, south, east, west and center) gave no observable change in measured momentum flux values with an experimental set up as Figure 3 and a flow rate of 25 ml/sec.

The influence of the gravitational field was tested, with the same flow rate, by varying the distance from the flow probe to the measuring plate from 3 to 5 to 7 cm. No detectable differences in momentum flux values were recorded.

The importance of exit angle is seen in Table 1. Distance from flow probe to measuring plate was about 3 cm. Angles were measured as exactly as possible, the estimated error being ± $5^{\circ}$.

With a horizontal flow probe the apparatus measured momentum flux 4.2 g.wt. and flow rate 20.5 ml/sec. The height h of the nozzle was 61 cm from the floor and from that position cast distance x was measured to be 66.5 cm.

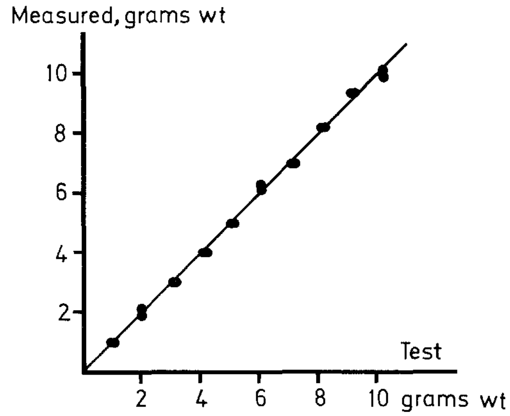


Fig. 4. Test with dynamometer. Force from dynamometer (test) and from momentum flux meter (measured). Error range: -0.3 to +0.1 grams wt. Error mean: -0.05 grams wt. Error SD: ±0.11 grams wt

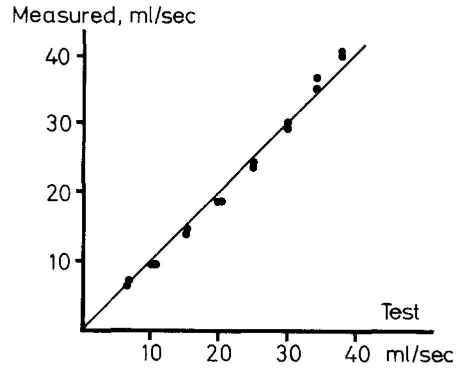


Fig. 5. Test with steady flows. Flow rate from electromagnetic flow meter (test) and from DISA flow meter (measured). Error range: -1.5 to +2.3 ml/sec. Error mean: -0.05 ml/sec. Error SD: ±1.25 ml/sec

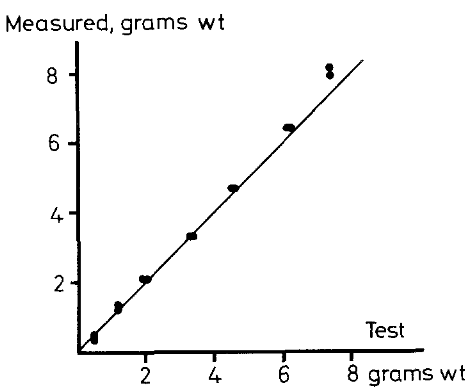


Fig. 6. Test with steady flows. Force calculated from rigid nozzle diameter and flow rate from electromagnetic flow meter (test) and from momentum flux meter (measured). Error range: -0.2 to +0.7 grams wt. Error mean: +0.12 grams wt. Error SD: ±0.26 grams wt

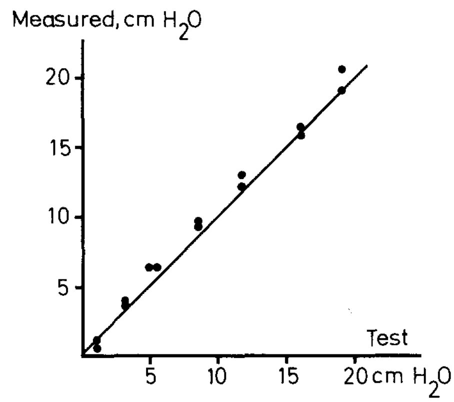


Fig. 7. Test with steady flows. Estr calculated from flow rate from electromagnetic flow meter and rigid nozzle diameter (test) and from momentum flux meter (measured). Error range: -0.8 to +1.7 cm $H_2O$. Error mean: +0.54 cm $H_2O$. Error SD: ±0.94 cm $H_2O$

From the cast distance the calculated velocity is

$$v = \sqrt{\frac{g \cdot x^2}{2\,h}} = 188 \text{ cm/sec}$$

where g is the constant of gravity 9.82 cm · sec$^{-2}$

From the momentum flux meter

$$v = \frac{M}{rho \cdot Q} = 201 \text{ cm/sec}$$ taking the density

rho as 1 g/ml. The difference between these calculated results is 6.5%.

DISCUSSION

Accuracy. For all static accuracy tests presented it has to be kept in mind that the test procedure

Table 1. Different stream exit angles

| Exit angle (a) | Momentum flux grams wt. | Measured error % | Expected error (1-cos(a))·100% |
|---|---|---|---|
| 0° | 3.2 | 0 | 0 |
| 10° up | 3.1 | 3.1 | 1.5 |
| 10° down | 3.1 | 3.1 | |
| 20° up | 3.0 | 6.3 | 6.0 |
| 20° down | 2.6 | 18.8 | |
| 30° up | 2.7 | 15.6 | 13.4 |
| 30° down | 2.5 | 21.9 | |

itself is not without errors although they have been minimised as much as possible.

The dynamometer set-up is a test of the momentum flux transducers and the recorders. The errors presented are not important.

With the flow probe horizontal the measured results fall within an acceptable range of error. Expressed as a percentage of full scale used for the test, maximum errors are all below 10% (Figs. 5 to 7 and for cast distance). The location of the impact on the plate and the influence of the gravitational field are unimportant. Splash back from the plate cannot be important.

Different stream exit angles (above 10-15$^{o}$) can cause great errors. The shelf for penis support should minimise this problem, but one should be aware of the uncontrolled exit angle in the event of metal abnormality. Retraction of the prepuce is extremely important to avoid enormous artefacts in the exit area.

In clinical use measurements are usually made on flows varying in time. The extra sources of error affecting such dynamic measurements are: (i) the fact that the basic equations are strictly true only for constant flow; (ii) the finite and unequal time constants of the momentum flux meter and the flow meter; (iii) the time delay between the measurement of momentum flux and that of flow rate. Preliminary observations suggest that none of these errors should be important at maximum flow, since this in most cases is maintained for at least 2 sec.

The apparatus may have to be improved to yield reliable measurements throughout micturition.

Interpretation. From the equations given in the section on material, it follows that during constant flow

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

In the case of a stream discharged from a rigid nozzle, the cross-sectional area A of the stream is the same at different flow and approximately equal to that of the nozzle. Therefore the momentum flux M is proportional to the square of the flow rate Q, and so a graph showing values of M plotted against corresponding values of Q should be a parabola, from which the area A can be calculated. We have verified that this is so in practice. In the case of the male urethra the stream cross-section A becomes larger at high flow rates, as the meatus is distended (9). Therefore a graph of M against Q should no longer be parabolic. The departures from the parabolic form give information about the distensibility of the metal part of the urethra. In each case, then, measurements of momentum flux and flow rate give information about the rigid nozzle or distensible meatus from which the stream is discharged.

We believe that this is the most straight forward and useful way of interpreting clinical measurements.

In addition one may calculate the residual energy density Estr in the stream and hence the energy loss (Pves - Estr) suffered by unit volume of fluid in flowing through the urethra. This in turn may be converted to the energy loss factor (Pves - Estr)/Pves introduced by Bottacini et al. (1). However, flow through highly distensible tubes such as the urethra has peculiar characteristics (5). For example, it is certainly possible that dilation of the meatus may reduce the stream speed and residual energy density, and so paradoxically increase the energy loss, for the same bladder pressure and flow rate. Therefore great caution has to be exercised in the interpretation of Estr and the energy loss factor, and in comparing their values in different patients.

## CONCLUSION

In vitro testing of the momentum flux meter shows that, for steady flow rates within a range to be expected in patients, its accuracy is acceptable for clinical evaluation and research of meatal properties in male patients.

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Dr. H. H. Meyhoff
Department of Urology
Herlev Hospital
DK-2730 Herlev
Denmark