An ultrasonic urine sensor

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H. Kodama, H. Yoshimura, Y. Nagata. An ultrasonic urine sensor. Gerontechnology 2009; 8(1):35-37. doi:10.4017/gt.2009.08.01.008.00. An ultrasonic urine sensor has been developed for measuring urine accumulation in the human bladder. Observations have been made on the bladder expansion process under gradual accumulation of urine by using a magnetic resonance imager. After a clinical test to evaluate the principle of measurement, the sensor has been commercialized. In its present form, the sensor can be used by medical specialists to assess the bladder function, including for older patients.

Keywords: urine incontinence, technological aid, ultrasonic sensor

The European Silver Paper stresses the incorporation of technical aids in all aspects of care of older persons in order to maintain independence, autonomy and a high level of quality of life[1]. Urinary control is important for human dignity[2]. Urinary incontinence annoys both individuals themselves and their families and caregivers[3]. An ultrasonic urine sensor detects the bladder volume from the abdominal skin surface and is useful to assess the individual bladder function[4]. Here such a sensor is described for use by medical specialists[5].

The measurement principle of the sensor is based on the anatomical features of the bladder. It is located inside the pelvis with intakes from the left and right ureters from the kidneys, and a discharge via the urethra (*Figure 1*). At the bottom of the bladder the urethra forms the apex of a triangle of these three urinary tracts. This bladder triangle is fixed to the pelvis with tendons that are more rigid compared to other parts of the bladder wall.

The shape of the empty bladder is like a bendable disk of which the upper part shrinks over the bottom part including the triangular part during emptying. With urine accumulation the bladder is enlarged mainly upwards pushing up and out the small intestine, slightly forward towards the abdominal surface thus pushing out parts of the small intestine and slightly backwards pushing toward the large intestine or uterus. The bladder bottom maintains its shape in all stages of filling and emptying. Therefore, in principle, the urine accumulation in the bladder can be estimated by its bottom area multiplied by its height. This has been confirmed by a MRI experiment of 10 subjects (*Figure 2*). Thus the bladder volume can be estimated from equation [1]

$$PD = \sum_{i=1}^{n} P_i * D_i \qquad [1]$$

where P_i are the intensities (dB) of the echoes reflected from the rear wall of the bladder reflecting bladder width, D_i, the distanc-

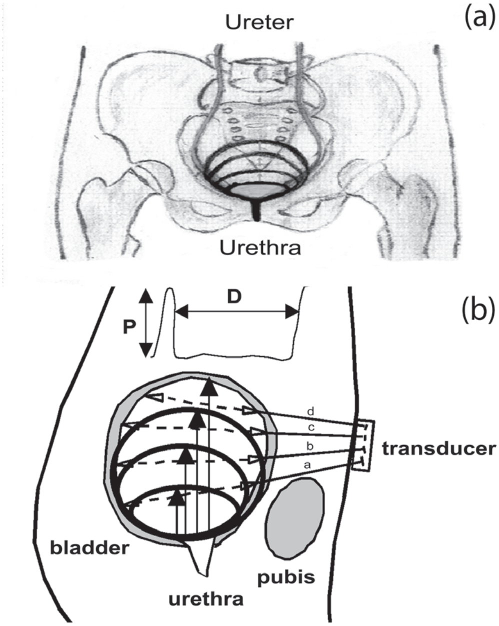

Figure 1. Overview of the lower abdomen and the ultrasound echo during the filling of the bladder when it enlarges mainly upwards, slightly anteriorward and slightly backward; (a) Anterior view; left and right ureters and an urethra connect to the bladder triangle or bladder bottom; (b) Lateral view of ultrasonic assessment; a, b, c, and d are ultrasound beam lines; P is the intensity of the ultrasound echo reflected from the rear wall of the bladder; D is the distance between the back wall and front wall of the bladder; the curve on top is a schematic picture of the time function of the reflecting signals with P echo intensity indicating bladder width and D duration between echos from front and back walls

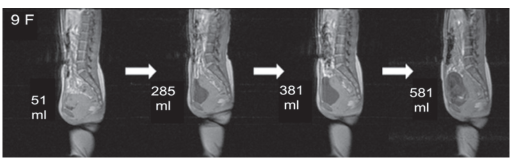

Figure 2. Different shapes of full bladder and bladder filling in one of the ten subjects in the MRI experiment; bladders are mainly filled in an upward direction; the shape of a full bladder differs but the bladder bottom remains in place; subject exercised chest respiration to avoid artifacts of the abdominal region in MRI recording

es (cm) calculated from the time differences between the echoes reflected from the back wall and front wall of the bladder reflecting bladder depth, and n, the number of ultrasonic beams arrayed cephalically reflecting bladder height. In our case, n=4.

In order to evaluate this principle of bladder measurement, a clinical test was carried out in the Spinal Injuries Center of Japan. Simultaneous examination of cystometry (flow dynamics and its relationship with the pressure in the bladder), X-ray examination (bladder shape and location) and measurement of the amount of physiological saline water in the bladder were carried out in close cooperation with 23 persons, 20 men and 3 women. For 20 persons (87%) a definite monotonic relationship between urine accumulation in the bladder and the corresponding measurement index was found. For the three other persons, shape and location of the bladder was irregular, although with adjustment of the location of the ultrasonic beams a monotonic tendency was obtained.

However, it should be pointed out that the signals reflected from the bladder appear to be very noisy due to probably the inherent characteristics of the ultrasound waves. This kind of phenomena has been found in all kinds of measurements for internal organs of human beings with the application of ultrasound beams.

To solve this problem, two steps of averaging were taken. First, raw data was reviewed for outliers, and outliers were replaced by interpolated values. Subsequently a running

Table 1. Error analysis of the test results of the relationship of bladder volume and the amount of urine voided, by one person in 29 instances within 8 days; All measurements fall within the acceptable range of ±15% or 20ml

Error range %	Times voided	% in Range	Average error %
5	12	41.4	2.23
10	21	72.4	4.34
15	28	96.5	6.38
20	29	100.0	6.72

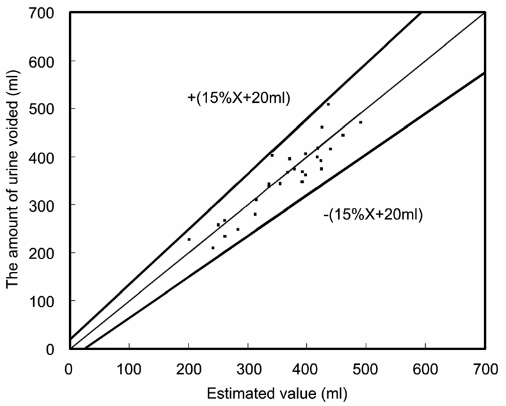

Figure 3. Relationship between the estimated bladder volume and the amount of urine voided by one person in 29 instances during 8 days; least squares method is used for fitting; all measurements fall within the ±15% or 20 ml interval of the fitted curve

average of calculated over 5 values. This yielded a smoothed measurement index, PD. The urine accumulation in the bladder could then be calculated more easily by the following equation [2][6].

$$V = C_0 * PD + C_1 \quad [2]$$

where C_0 and C_1 are the constants that specify the underlying characteristics of each user estimated with the least-squares regression method. Data analysis of 8 days and totally 29 times of urine voiding of one person

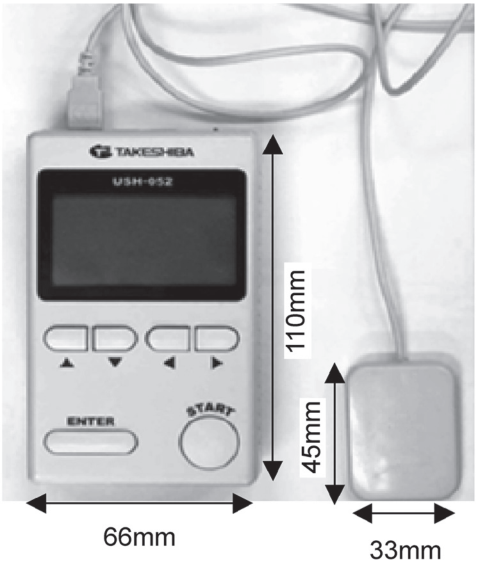

Figure 4. The commercially available ultrasonic urine sensor Yuririn USH-052[9]

showed that the measured urine accumulation values fall into the acceptable region of ±15% or 20 ml (*Figure 3, Table 1*).

The ultrasonic urine sensor was patented in 2004[7] and permission was given for its medical applications in Japan[8]. The ultrasonic urine sensor is commercially available as Yuririn USH-052[9] (*Figure 4*).

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