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Experimental Investigations on Intracavity Sonography

Part 1: Alteration of Imaging by Variation of the Contents of Rigid Hollow Receptacles or Isolated Porcine Urinary Bladders

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Summary. Multiple artifacts may occur in the diagnostic application of sonography. Occasionally, these may make it difficult to differentiate real tissue structures. In order to investigate the imaging properties of ultrasound in intracavity investigation techniques, we have examined the imaging under different conditions in rigid hollow receptacles as well as in an isolated porcine urinary bladder. A measurable difference of sound conduction depended on the characteristics of the fluid (sound conductor): furthermore, accumulation of air in the hollow space lead to various interfering echos. The importance of a central position of a sound source for obtaining useful sonograms in intracavity ultrasonographic diagnosis was evident.

Key words: Intracavity sonography, Experimental investigations I, Variation of the media, PVC hollow receptacles, Isolated porcine urinary bladder, Sound conduction alterations.

Introduction

Sonographic investigations play an increasing role in the differential diagnosis and follow up of tumors, inflammatory conditions and anatomical anomalies [1–6, 8, 9]. The principle of this imaging is based on a reflection of sound impulses at interfaces between areas of differing sound resistance (impedance). The ultrasonographic signals received from various directions and distances are converted into visual information (A or B image) [1, 7]. However, interference echos or artefacts may be produced which do not correspond to any real tissue information and which must be recognized before diagnosis [10]. In order to investigate the imaging properties of ultrasound, we tested sound conduction in a rigid hollow receptacle and in an isolated pig urinary bladder with different contents (fluid/air). These experimental investigations were intended to provide answers to the following questions: How does the ultrasonographic image change with

a) displacement of the sound source towards the reflection surface?

b) different physicochemical composition of the fluid ("sound conductor")?

c) addition of graduated amounts of air to the urinary bladder?

Methods

Description and Function of the Instrument

A realtime ultrasonograph (type 3406) from Brüel & Kjaer (Denmark) was used in our investigations. It consists of:

a) the scanner

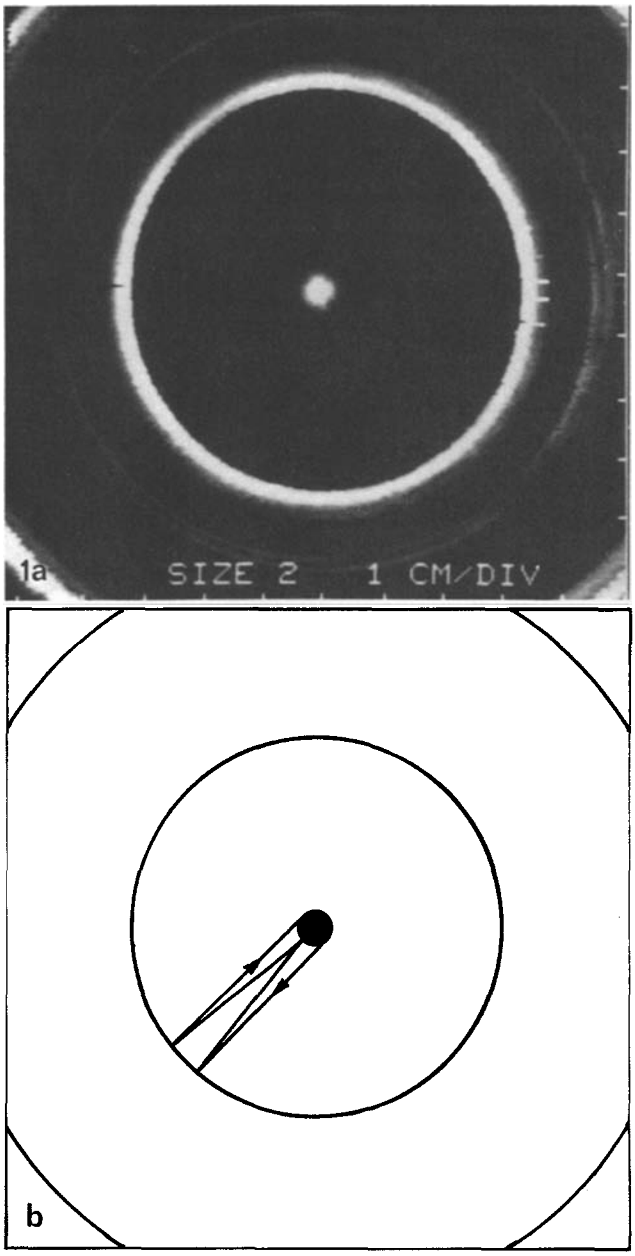
b) the ultrasonograph with a monitor on which the dynamic ultrasonogram is projected

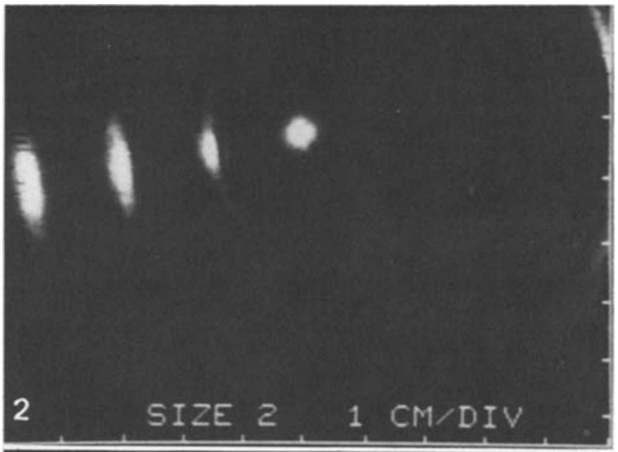
c) a camera attached to the monitor to provide documentation (photographs of the ultrasonograms)

The scanner consists of a probe on which a 5.5 MHz ultrasonic head can be attached. The probe has a diameter of 7 mm (21 Ch.). This transducer can be rotated by a motor located in the probe handle; rotations of about 2 to 6/s can be regulated continuously. For the experiments with an isolated porcine urinary bladder, a cystoscope sheath (24 Ch.) was used to introduce the sound source into the lumen of the bladder. This sheath also enabled exact introduction of a quantifiable amount of fluid. With the beginning of the rotation of the transducer, sound impulses were emitted at an angle of 90°. After processing of the ultrasound reflections, 360° tomograms of the investigated hollow body were produced. By linear movements in the axis (PVC cylinder) or of the resectoscope sheath (urinary bladder), the position of the transducer could be altered as desired, so that transverse sectional images of various regions of the wall (reflection surface) could be visualized.

Experimental Procedures

Sonography in Rigid, Fluid-Filled Hollow Spaces. A PVC cylinder (internal diameter: 6.63 cm) was filled with various fluids (NaCl





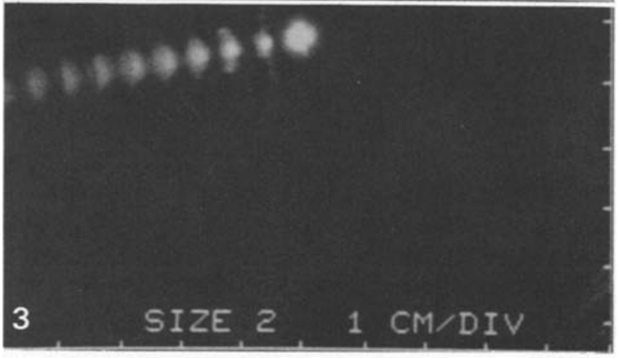


Fig. 1a, b. Sonogram of a PVC cylinder (a) filled with NaCl solution (0.9%) with a central position of the transducer. **b** "Sound path" of the multiple reflections of first order to Fig. 1a (for illustration of parallel sound paths)

Fig. 2. Wall reflections of a PVC cylinder in eccentric displacement of the sound source; multiple reflections of first and second order

Fig. 3. When the transducer moves closer to vessel wall (cf. Fig. 2a), representation of multiple reflections of first, second and further orders; their distances from each other, corresponding to the distance of the transducer from the receptacle wall

0.9%; human albumin 5%, 20%; glucose 5%, 10%, 20%, 30%, 40%, 50%; whole blood; erythrocyte concentrate; blood-NaCl 0.9% (1 : 1). The sound source was localized both in the center and eccentrically. The different sonograms were documented and evaluated.

Sonography of the Isolated, Fluid-Filled Porcine Urinary Bladder. A freshly removed pig bladder was filled with various fluids. The fluid was displaced by air to various extents. Different sonograms of the bladder were documented with a central as well as an eccentric position of the sound source.

Results

Reflection Phenomena in Rigid, Fluid-Filled Hollow Receptacles

After filling of the PVC cylinder (internal diameter: 6.63 cm) with physiological saline solution, the sound source inserted in the axis was caused to rotate. The emitted sound impulses hit the wall perpendicularly over the entire circumference. It can be seen in Fig. 1a that the major proportion of the sound energy is reflected back to the sound source (impulse receiver) and registered there. The even brightness of the wall imaging indicates that the extent of reflection is almost the same on all parts of the inner wall when the sound source is located in the middle.

At twice the distance from the transducer, a second circle is represented which does not correspond to a real structure. It results from a "multiple reflection" (first order) in the inner surface of the receptacle wall. In this case, it requires twice the time for visualization, and thus also has twice the distance from the sound source with regard to its pictorial representation. The corresponding sound path is illustrated in Fig. 1b.

Table 1. Dependence of the area of the cylinder tomogram on the characteristics of the receptacle filling

Liquid	Area (cm²)	Reduction of area (%)
Sodium chloride 0,9%	32.90	0
Human albumin 5%	32.39	1.6
Human albumin 20%	30.38	7.6
Glucose 5%	32.49	1.2
Glucose 10%	31.68	3.7
Glucose 20%	30.28	8.0
Glucose 30%	28.63	13.0
Glucose 40%	27.02	17.9
Glucose 50%	25.29	23.1
whole blood	29.79	9.5
Erythrocyte concentrate	28.44	13.6
Blood-Sodium chloride (1:1)	30.98	5.8

Table 2. Dependence of the area of the bladder sonogram on the characteristics of the bladder filling

Liquid	Area (cm²)	Reduction of area (%)
Sodium chloride 0,9%	26.19	0
Human albumin 5%	25.58	2.3
Human albumin 20%	24.37	6.9
Glucose 5%	25.19	3.8
Glucose 10%	24.72	5.6
Glucose 20%	24.14	7.8
Glucose 30%	23.67	9.6
Glucose 40%	22.39	14.5
Glucose 50%	20.87	20.3
whole blood	24.49	6.5
Eryhtrocyte concentrate	23.32	11.0
Blood-Sodium chloride (1:1)	24.25	7.4

In eccentric displacement of the sound source towards the receptacle wall, the sound only hits the wall perpendicularly in the region of the displacement line. In the areas deviating from this line, most of the reflected sound did not reach the impulse receiver. The corresponding parts of the wall were imaged poorly (Fig. 2). On the other hand, in the extension of the displacement line beyond the sound source, a "dense" wall region (similar to a brace) was evident. Accordingly, the multiple reflection images were no longer circular, but a proper image of this brace.

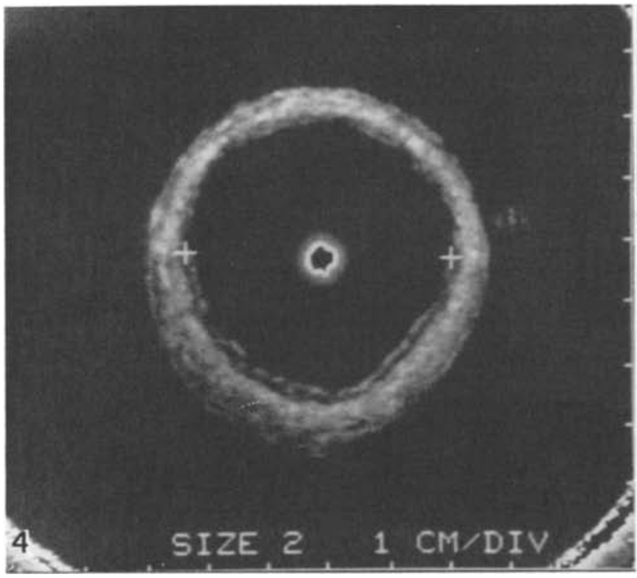
The nearer the sound source is brought to the receptacle wall, the closer together are these artefacts. They are correspondingly numerous and finally form a proper pathway (Fig. 3).

Sound Conduction in Fluids of Different Electrolyte and Protein Contents

When the PVC cylinder was filled with different fluids, the dependence of the rate of the sound transmission on the conducting material (fluids) was evident. The differences were measured by the diameter of, or the area of the cylinder image (tomogram) and are reproduced in Table 1. In higher specific weight of the fluid, a regular reduction occured in the size of the cylinder sonogram.

Reflection Phenomena of the Porcine Urinary Bladder as Well as the Results of Filling it With Fluids of Different Physicochemical Composition

Independent of the fluid quality used for filling, there was also representation of a circular reflection band which cor-



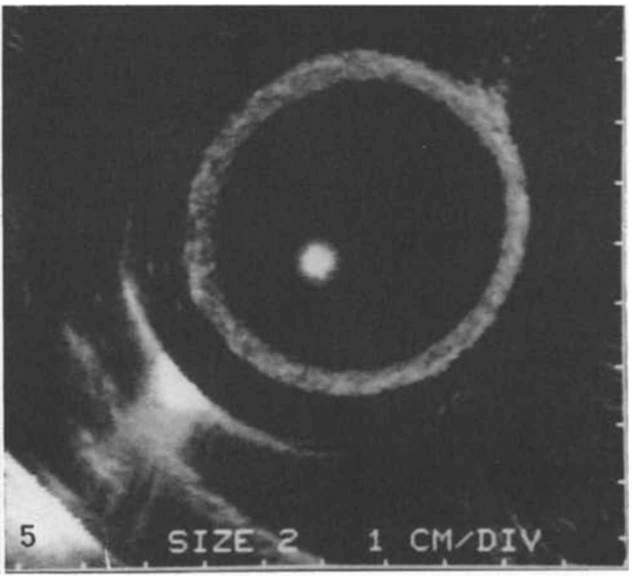
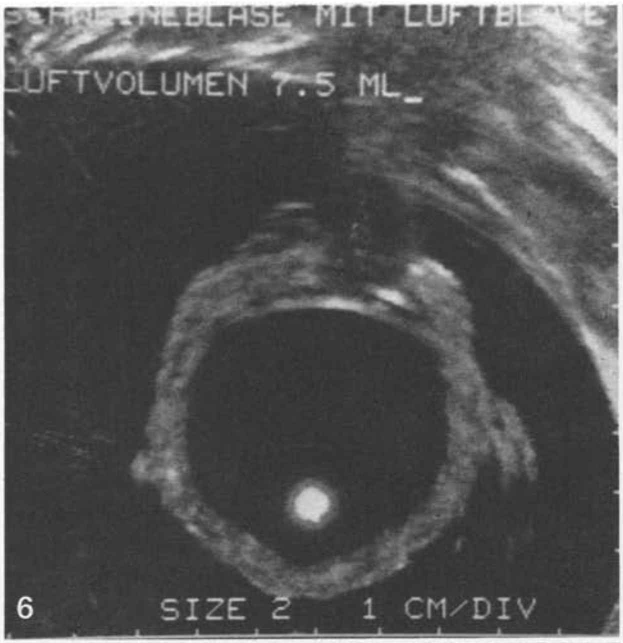
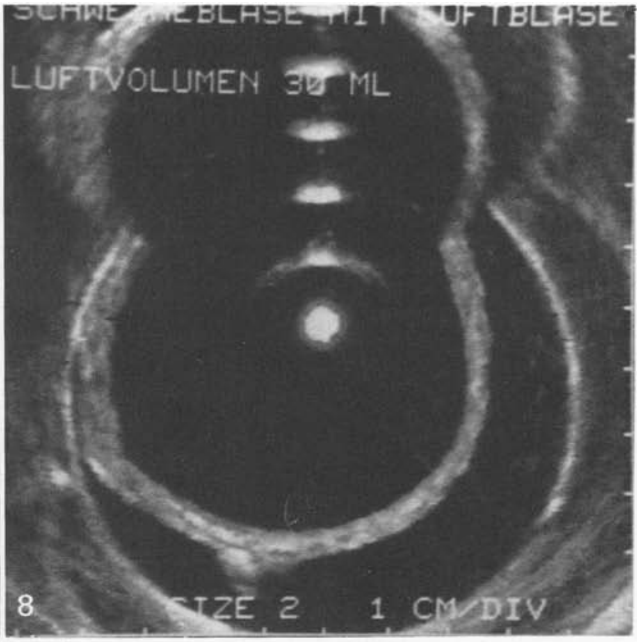


Fig. 4. Sonogram of the porcine urinary bladder in filling with NaCl solution (0.9%) and central position of the transducer

Fig. 5. Sonogram of the porcine urinary bladder in with NaCl solution (0.9%) and eccentric displacement of the sound source





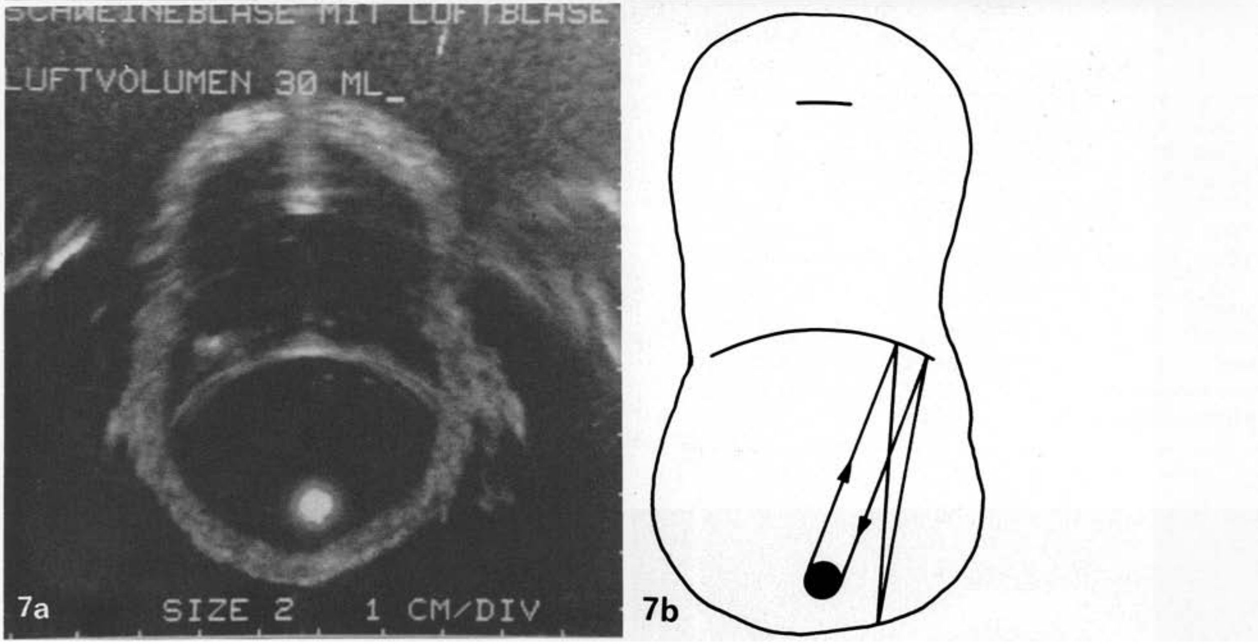


Fig. 6. Sonogram of the porcine urinary bladder in filling with NaCl solution (0.9%) and addition of 7.5 ml of air

Fig. 7a, b. Sonogram of the pig urinary bladder (**a**) in filling with NaCl solution (0.9%) and addition of 7.5 ml of air. **b** "Sound path" for explanation of the reflection artefacts in Fig. 7a

Fig. 8. Sonogram of a pig urinary bladder after filling with NaCl solution (0.9%) and addition of 30 ml of air; in consequence of the near position of the transducer to the air-water boundary, numerous multiple reflections arise

responded to the entire bladder wall (Fig. 4) even in the porcine urinary bladder with an almost central position of the sound source. Differentiation between mucosa and musculature is possible in most areas.

The eccentric displacement of the transducer did not reveal the attenuation of reflection in the parts of the wall lateral to the line of displacement compared to the experiments with the rigid PVS cylinder (Fig. 5). The cause of this was nonhomogeneity of the reflection surface in the region of the bladder wall.

Analogous to the filling of the PVC cylinder with fluids of different physicochemical composition, the alteration in size of the planimetrically registered bladder tomograms (including the bladder wall) were analyzed. As in the fluid-filled rigid body, a reduction of the area in a graduated sequence was also observed (Table 2). It is impressive (20.3%)

with 50% glucose as compared to filling with physiological saline. However, unavoidable alterations in the deformity of the bladder lumen during the investigation must be taken into account in the results.

Results of Successive Air Inflation of the Initially Water-Filled Pig Bladder

After stepwise addition of 7.5 ml aliquots of air into the bladder filled with 100 ml of physiological saline within a Bülau cylinder likewise filled with physiological saline, a total reflection at twelve o'clock (site of the air which has risen and which was collected above the fluid) occurred with the smallest amount of air (7.5 ml) (Fig. 6). Consequently, the bladder wall behind this area could not be visualized. After a further increase in the amount of air, there was a displacement of the sound source into the immediate vicinity of the bladder wall at six o'clock due to the distension of the entire organ preparation. The total reflection at twelve o'clock persisted.

In filling with 30 ml of air (Fig. 7a), a double reflection occurred in the air bladder which resulted in mirrorlike and distored imaging of the fluid-filled part above the air bladder. In addition to the mirror phenomenon, numerous multiple reflections were observed above the air bladder. The scheme in Fig. 7b illustrates the causal sound path of the reflections.

Multiple reflections were particularly numerous in the cases in which the transducer was located very close to the boundary between air and water (Fig. 8).

Discussion

Discussion of the Physical and Technical Basis of Intracavity Sonography

In medical diagnosis, sonography is based on the following physical principles:

Sound waves are mechanical oscillations comprising a large frequency range. The range from 16,000 to 10^{10} oscillations/s is designated as ultrasound. In contrast to electromagnetic oscillations such as light and X-rays, which can be propagated even in a vacuum, the propagation of ultrasound is linked to material; it thus only takes place in solid and fluid receptacles and to a limited extent also in gases. In relation to sound propagation, the human body behaves like a viscous fluid [7]. If the sound wave reaches an interface separating two media with different acoustic properties, a proportion of the waves is reflected whereas the rest continues on its path. The ratio of the reflected to the incident energy is designated the degree of reflection. The percentage of reflecting energy will be greater, the greater the respective impedances of the contiguous media from each other. An almost complete reflection of the ultrasound wave occurs at the boundary between tissue and air, or tissue and bone. This was also significant for the ultrasonographic investigation in our experiments to the extent that tissue which is located behind an air layer could no longer be visualized sonographically. This phenomenon of complete reflection could be clearly shown in our experiments with the isolated porcine urinary bladder (Fig. 6, 7a, 8). In addition, it was associated with an almost complete mirroring of the bladder wall regions visualized in real terms. In this way, it gave rise to an impression of a continuation of the bladder lumen (Fig. 7a). In most cases, we were able to verify these artefacts by shifting the transducer.

When sound falls obliquely on an interface, the angle of reflection corresponds to the incident angle (Snellius principle). Since the sound source also functions as sound receiver, in the ideal case of investigation the sound wave should hit the inferface perpendicularly [7]. In our experiments with the centrally or eccentrically positioned sound source in the rigid, fluid-filled hollow cylinder, the great significance of this initially theoretical demand became clearly visible.

The principle of ultrasonographic investigation consists of transmitting short ultrasonic impulses into the body and investigating the reflected echo. A cathode ray oscilligraph is suitable for visualization of the high-frequency signal converted in the impulse receiver. In the representation of the echo, we distinguish in principle between the A image and the B image. In the A image, the echos are represented as vertical deflections ("spikes") along the baseline of the oscillograph; in the two-dimensional B image technique we used, the imaging takes place by lateral displacement of numerous one-dimensional echo images which penetrate the investigated object and are arranged side-by-side [7]. The B image thus corresponds to a section image of the investigated region, analogous to tomography. The "compound technique" or "slow" B image contrasts with the "rapid" B image (realtime technique).

In intracavitiy sonography, we prepared 360° tomograms of the vicinity of the transducer in the "rapid" B image technique in these tomograms. Instead of xy coordinates, "polar coordinates" were used on the cathode ray oscilligraph. The image thus attains a great similarity to radar pictures.

Discussion of the Experimental Findings

In the diagnostic application of intravesical sonography, the reflected sounds occurring require critical interpretation. Images which correspond to real structures must be separated from artefacts [10]. Sound conduction, refraction, reflection, absorption and scatter may influence the image in accordance with the physical situation. Phenomena such a "sound extinction" and "echo-plus effect" must be considered.

Our experimental investigations have shown that the following parameters are of crucial importance for the sonographic image:

1. The characteristics of the "sound conductor" (composition of the fluid in the rigid hollow receptacle or in the isolated urinary bladder): the higher the specific weight or the molarity of this fluid, the more rapid is conduction and the smaller the sonographically measurable cavity or bladder diameter appears to be.

2. Moving the sound source in the hollow receptacle: in an eccentric position (to some extent, nonperpendicular incident sound angle) the same reflection does not take place from all areas of the investigated object. In eccentric position of the transmitter crystal in the rigid hollow receptacle with a homogenous inner surface, only those wall areas are reproduced on which the ultrasound falls perpendicularly; the remaining areas are shown up as dark. A comparable effect could not be observed in our experimental investigations on the pig bladder, since the bladder wall consists of numerous very small reflection surfaces of varying arrangement and sufficient wall regions perpendicular to the incident sound are thus always present irrespective of the position of the sound source. A perpendicular incidence of the ultrasound in transurethral bladder diagnosis is nevertheless required, since the division between a pathological lesion, the bladder wall and the perivesical tissue can be optimally recognized only in this case. Furthermore, it is important that with the sound source eccentrically positioned interfering sound artefacts (multiple reflections etc.) may occasionally occur. These may be confused with normal tissue reflection or may have a major interference effect. By an alteration of the transducer position, a distinction can be achieved between apparent and real tissue reflections in cases of doubt.

3. The avoidance of an air admixture in filling of the bladder (enlargement of the air bladder) above and beyond the physiological extent. This likewise contributes to preventing sound artefacts.

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