POLSKI
PRZEGLĄD CHIRURGICZNY
2012, 84, 10, 535–545
10.2478/v10035-012-0090-4

REVIEW PAPERS

HISTORY AND FUTURE DIRECTIONS IN ULTRASONOGRAPHY

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The beginnings of ultrasonography

The development of ultrasonography would not be possible without the earlier findings concerning ultrasounds. As early as the thirteenth century Lazzarro Spalanzani observed that bats use hearing rather than sight, considering location in space. In 1938, Donald Griffin described the phenomenon of echolocation in these mammals. In 1880, Pierre and Jaques Curie showed the piezoelectric phenomenon consisting in the creation of an electrical charge inside the crystal quartz or Seignette's salt (sodium and potassium tartrate), under pressure (1). The name of the phenomenon is derived from the Greek language meaning 'to push'. The Curie brothers also observed the inverse piezoelectric crystal vibration phenomenon involving the effect of an external electrical field. Piezoelectricity is only present in the crystals, being elementary cells, which do not have a center of symmetry, such as quartz crystals.

In the first half of the 20-th century the sonar was constructed-a device using sound waves to track and classify mobile and immobile submerged objects. The first idea for such a device was patented by an English meteorologist, Lewis Richardson in 1912, and one year thereafter, by Alexander Behm in Germany. In 1941, Sproule and Firestone working independently, constructed a device that used ultrasounds to detect defects in the hull of vessels (1). The designed 'supersonic reflectoscope" by Firestone was soon adapted for the use in shipbuilding. Christian Andreas Doppler (fig. 1), an Austrian physicist and mathematician was the first in 1842 who described the color change under the influence of movement in the system of submerged stars. This effect consists in the development of frequency differences sent by the source and recorded by the observer, who moves in relation to the source, being applied in ultrasonography. Shigeo Satomura was the pioneer of Doppler ultrasonography, a physicist from the Univer-



Fig. 1. Christian Doppler (1803-1853) (Source: Woo Joseph- A short History of the development of Ultrasound in Obstetrics and Gynecology – http://www.ob-ultrasound.net)

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sity of Osaka, who in 1956 demonstrated that the Doppler signal is generated by the movement of heart valves (1). All the above-mentioned findings opened the door for the use of ultrasound waves in medical diagnostics.

At the end of the thirties of the 20-th century, Karl Theodore Dussik (fig. 2), a psychiatrist and neurologist, along with his brother Friedrich tried to take advantage of ultrasound waves in clinical practice. The Dussik brothers in 1937 determined the amplitude of the signal obtained while scanning the human brain- the derived images were called "hyperphonograms", and the observed weak signal areas corresponded to the lateral chambers of the brain (1). Karl Dussik postulated the possibility of detecting brain tumors by means of ultrasound. However, Guttner analysed his results and demonstrated in 1952 that the signal variation was connected with differences in the thickness of the bones of the skull.

In the forties of the past century many authors once again recognized the potential of ultrasound waves, and the possibility of their use in medicine. Ludwig and Struthers determined the velocity of ultrasounds in soft tissues at 1540 m/s and visualized the previously implanted concrements into the muscles and gall-bladders of dogs (1, 2). Due to their employment in the military their study results were not published. In the United States, three physicians were pioneers of ultrasonography: John Julian Wild – a surgeon who emigrated from England to the US after World War II, George Ludwig – an internist, and Douglas Howry – a radiologist (1, 3). John Wild used a transducer of a frequency of 15 MHz for the assessment of colon wall thickness in patients previously immersed in a water tank. This method was intended to be used to differentiate mechanical and paralytic obstruction. In 1952, Wild recognized the recurrent femoral tumor and malignant breast cancer by means of ultrasound. However, due to the subjective evaluation of the obtained image the results were not confirmed by other authors. Wild was the first to use an intra-anal and intra-vaginal ultrasound probe. Douglas Howry was head of the research project which was intended to show soft tissue images using ultrasound waves. In 1949, he used elements of a radio and aircraft radar to construct an ultrasound scanner, where the waves were emitted in a pulsating manner. In 1950, he registered the first transverse sections of organs obtained via ultrasound by means of a camera. Limitations of the above-mentioned device were connected with the possibility of obtaining only structures perpendicular to the ultrasound beam, thus, the resulting image was not of high quality (3).



Fig. 2. Karl Theodore Dussik (1908-1068) (Source: Woo Joseph- A short History of the development of Ultrasound in Obstetrics and Gynecology – http://www.ob-ultrasound.net)

In 1951, Howry along with two engineers constructed a complex ultrasound scanner in which the probe was attached to a wooden rail. The investigated object and probe were immersed in a water tank, in order to obtain a better image. Since patients' could not stay for a long time immersed in water, at the end of the fifties of the past century a semi-circular instrument was constructed, being attached to the patient with the probe immersed in a saline solution, which eliminated the need for total patient immersion. In the sixties of the past century, Douglas Howry and the following engineers: Wiliam Wright and Edward Meyer developed a scanner, which could directly adhere to the skin, and the position of the probe was regulated by the operator. Wright and Meyer established the Physionics Engineering

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Company, which developed a hand-held prototype ultrasound scanner.

In England, Ian Donald of the Department of Obstetrics and Gynecology, University of Glasgow was the precursor of the clinical use of ultrasonography. In 1958, he published an article demonstrating the benefits of ultrasonography in the diagnostics of abdominal cavity tumors. He described a case of a 64-year old female patient with abdominal pain, weight loss, and suspicion of ascites. Initially, the patient was diagnosed with advanced stomach cancer, while Donald on the basis of ultrasonography recognized a large cyst, which was successfully excised. The histopathological examination confirmed the presence of a benign ovarian cyst. Additionally, Ian Donald and his colleagues demonstrated that a filled gallbladder is an excellent acoustic window for the presentation of minor pelvis organs, enabling the visualization of small pelvic tumors, ectopic pregnancy, and location of the placenta (1).

In 1955, B. Jaffe discovered the piezoelectric properties of lead zirconate-titanate (PZT), which enabled the production of smaller probes in size. Such probes are used in the diagnostics of epidural hematomas in patients following head injuries. The method called midline encephalography was considered as a standard in patients following head injuries until the end of the seventies of the past century, and introduction of computer tomography.

During the sixties of the past century ultrasonography evolved from the stage of interest to a recognized diagnostic method, providing unique data (tab. 1). The initial skepticism towards this method resulted from the difficulties of interpreting results by radiologists, who were accustomed to describing X-rays, large ultrasound equipment, and lack of capability of viewing the lungs, bowels and bones.

Presentation A

The first attempts of imaging organs by means of presentation A took place in the thirties of the past century, and as previously mentioned by the Dussik brothers, were connected with the evaluation of the brain. Since the fifties of the past century we began to use ultrasound, in order to obtain images of other organs. Wild and Reid in 1953 were the first to use intraoperative ultrasound (IOUS), in order to visualize pathological tissues: they assessed a malignant brain tumor in the A presentation (4). In the sixties of the past century, IOUS was used more often in the determination of kidney stones, gallstones and brain tumors. In 1961, Schlegel successfully performed IOUS during pyelolithotomy. He used a 1.6 MHz frequency probe and removed small concrements, which were undetectable during palpation. In 1953, Wagai and co-authors were the first to use a 5MHz probe for the intraoperative evaluation of cholelithiasis (4). In 1963, Knight and Newell proposed the evaluation of the biliary tract for the presence of concrements by means of the A imaging presentation. Eiseman two years later used a probe, 2.5 cm in diameter, for the assessment of the extrahepatic biliary ducts, and a smaller probe (3mm in diameter), which was placed in the lumen of the intrahepatic biliary ducts for the visualization of stones.

Already in 1958, Yamakawa from Japan performed the first laparoscopic ultrasound

Table 1. Major findings in the early days of ultrasonography and the first use of ultrasound in medicine

Year	Author	Event
1842	*Doppler*	Doppler effect
1880	*Curie*	piezoelectric phenomenon
1912	*Richardson*	the first patent relating to the sonar
1937	*Dussik*	first cerebral ultrasound scanner
1938	*Griffin*	explanation of the echolocation phenomenon in bats
1950	*Howry*	first photographic paper recording of transverse sections of organs by means of ultrasound
1952	*Wild*	first evaluation of a femoral and breast tumor by means of ultrasound
1955	*Jaffe*	discovery of the piezoelectric properties of lead zirconate-titanate
1956	*Satomura*	Doppler effect caused by the movement of heart valves
1958	*Donald*	differentiation of intraabdominal tumors by means of ultrasound

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examination by means of the A presentation (4). The first breast ultrasound (A presentation) was performed by Wild and Neal in 1951: they described one benign and one malignant lesion on the basis of a self-constructed simple ultrasound device (5).

In the sixties of the past century first attempts were made to apply the A presentation in case of interventional procedures. In 1961, Berylne described the use of A presentation imaging ultrasound during kidney biopsy (6). Joyner in 1967 used ultrasound to determine the location of the puncture and aspiration of the pleural fluid. One year thereafter, Alfred Kratochwil in Vienna developed a probe enabling the safe performance of ultrasound-guided amniocentesis by means of the A presentation. In 1972, at least 7 articles concerning the use of ultrasound during biopsy were published. Hans Holm, a Danish urologist described a special probe with a needle canal. A similar probe was used by an American radiologist, Barry Goldberg (6).

In Poland, the first ultrasound examination using the A presentation was performed by Jan Kulig, in order to assess cholelithiasis. He used a type EM-2 echoencephaloscope (1.5 MHz) produced by INCO in Warsaw, and intended for the study of the brain (fig. 3, fig. 4). The study published in the Polish Journal of Surgery (1976) showed that the ultrasound examination enabled to correctly diagnose cholelithiasis in 92% of investigated patients, and thus, the diagnostic accuracy of ultrasound was better than cholecystography and infusion cholangiography (2).

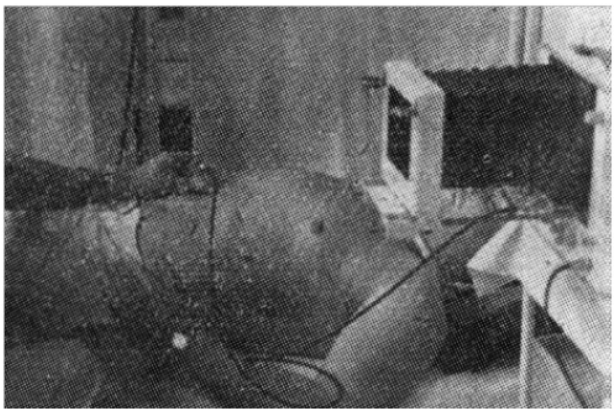


Fig. 3. Gall-bladder ultrasound by means of an EM-2 echoencephaloscope with the use of a 1,5 MHz probe (Source: Kulig J., Sobański M. Ultrasonograficzna diagnostyka kamicy pęcherzyka żółciowego. Polski Przegląd Chirurgiczny 1976;48:583)

Table 2 presented the pioneer ultrasound examination results using the A presentation.

Presentation B

The first ultrasound devices enabling the B presentation did not allow real-time imaging. In 1970, the only ultrasound device enabling real-time imaging was Vidoson produced by Siemens Medical Systems (3). The development of equipment and ultrasound techniques

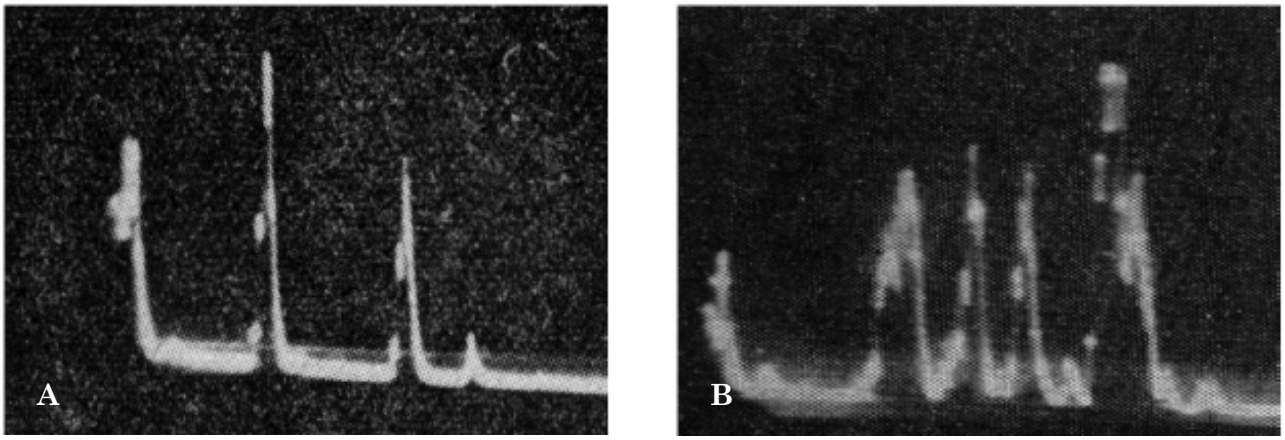


Fig. 4. A presentation ultrasonogram obtained in case of a normal gallbladder without stones. The first deflection corresponds to the reflection from the anterior abdominal wall, while the second and third deflection are derived from the gallbladder wall. (A). The A presentation ultrasonogram obtained in case of a gallbladder containing several medium-size stones (B) (Source: Kulig J., Sobański M. Ultrasonograficzna diagnostyka kamicy pęcherzyka żółciowego. Polski Przegląd Chirurgiczny 1976;48:583-584)

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Table 2. First ultrasound imaging –presentation A

Year	Author	Event
1951	*Wild, Neal*	first breast ultrasound in presentation A
1958	*Yamakawa*	first laparoscopic ultrasound with presentation A imaging
1958	*Wagai*	intraoperative diagnosis of cholelithiasis using ultrasound
1961	*Schlegel*	intraoperative ultrasound in the detection of small, non-palpable kidney concrements
1961	*Berylne*	presentation A ultrasound during kidney biopsies
1963	*Knight, Newell*	intraoperative diagnosis of choledocholithiasis by means of presentation A ultrasound
1965	*Eiseman*	intraoperative diagnosis of intrahepatic choledocholithiasis by means of ultrasound
1967	*Joyner*	pleural fluid puncture under ultrasound control
1968	*Kratochwil*	amniocentesis by means of presentation A ultrasound

considering real-time imaging was observed in the seventies and eighties of the past century.

J. Stauffer Lehman in the USA was the pioneer of abdominal cavity and pelvic ultrasonography. He started clinical tests with the use of the ultrasound device manufactured by Smith Kline enabling B presentation imaging. The device possessed a probe immersed in a water tank, which was lowered onto the patients' abdomen. Lehman and his colleagues did not submit conclusions concerning the clinical usefulness of ultrasonography, due to the lack of satisfactory accuracy and repeatability of performed examinations (3). Further investigations concerning ultrasound in clinical practice were undertaken by Marvin Ziskin and George Evans from the Hahneman Medical School in Philadelphia. The team was joined by Barry Goldberg, a radiologist. Goldberg together with H. Holm, a Danish urologist were the first to develop the technique of fine-needle biopsy under ultrasound control in 1965 (6). Vidoson was first used by Hoffmann in 1966 and Hollander in 1968 for imaging the female pelvis. Vidoson displayed 15 images per second enabling the visualization of organs without a flicker. Fred Winsberg, a radiologist from the McGill University in Canada used the Vidoson device to visualize the pulsating aorta.

In the early eighties of the past century we finally managed to overcome the limitations resulting from the delay between the generation of ultrasound and organ imaging results. Real-time imaging enabled to perform ultrasound examinations, especially in patients with severe injuries. Additionally, in the eighties and nineties of the past century smaller, faster, and easier to handle ultrasound devices were developed. In 1970, American radiologists performed ultrasound examinations on the corpses of human beings, after the injection of physiological saline into the peritoneal cavity. In 1971, the first case of peritoneal cavity bleeding after blunt trauma was described on the basis of an ultrasound examination (7). Five years later American surgeons used ultrasound to determine the degree of splenic damage. The first publication concerning ultrasonography prepared by ER physicians was published in 1988. Until the mid-nineties research was conducted concerning the usefulness of ultrasound in the diagnostics of trauma patients. This resulted in the development of the FAST (focused assessment with sonography for trauma) technique, which in most centers replaced diagnostic peritoneal cavity lavage, and is included in the algorithm of patients following severe injuries (Advanced Trauma Life Support). As a result, FAST ultrasound is performed by trauma surgeons and ER physicians. In 1990, the American College of Emergency Physicians (ACEP) prepared the first training course concerning the use of ultrasound in ER departments. In 1995, the American College of Surgeons established the National Ultrasound Faculty unit, which developed a training system for surgeons and residents in the field of diagnostic ultrasound, considering trauma and intensive care patients. Over the past several years numerous studies were published concerning emergency ultrasound examinations performed in patients with abdominal aortic aneurysms, ectopic pregnancy, biliary duct and kidney pathologies, deep venous thrombosis. Nowadays, these conditions are an indication to perform emergency ultrasound.

The above-mentioned conclusions were based on the assumption that emergency ultrasound examinations should only be per-

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formed when its usefulness has been proven, considering proper patient treatment. Such an examination should be aimed at finding specific signs and not the full evaluation of all organs and anatomical areas. Signs which are easy to identify and are of clinical value: peritoneal cavity fluid, presence of a pregnancy bladder, pericardial fluid, or cardiac arrest. If you do not provide the benefits of emergency ultrasound the examination should be performed electively, after stabilizing the patients' condition.

Currently, it is recommended that the ultrasound examination be performed at bedside, and the ultrasound device should be an element of the ER. In many centers emergency ultrasound examinations eliminated the need to perform such diagnostic procedures as peritoneal cavity lavage or pericardiocentesis. The establishment of the center injection under ultrasound control is becoming a standard, especially in patients with low blood pressure and hemodynamically unstable. Emergency ultrasonography is of paramount importance in patients after cardiac arrest, penetrating chest wounds, and hypotension of unknown cause. In such patients most information is obtained after abdominal cavity ultrasound and echocardiography. However, each of these studies is performed by a different physician, which prolongs the duration of the examination. Ad hoc ultrasonography improves the ability to assess, diagnose and treat patients in the emergency department. Studies aimed at evaluating specific signs enabling to obtain information concerning specific questions should be performed by ER physicians.

Intraoperative ultrasound with B presentation imaging was first described by Cook and Lytton in the United States, and Makuuchi in Japan, in 1977 (4). Cook and Lytton used a 10MHz probe for the intraoperative identification of kidney concrements. Makuuchi used a linear probe (2.5 and 3.5 MHz) for the visualization of the liver and pancreas. The first intraoperative probes assessing the liver were also used by Makuuchi (I and T letter shape manufactured by Aloka) in 1979 and Akimoto (triangular probe manufactured by Toshiba) in 1981. Cook and Lytton used a Bronson-Turner probe, which was initially designed for ophtalmology (4). The first symposium concerning the use of IOUS took place in Paris in 1982, and ever since has become the standard examination, considering patients subject to liver resections. Nowadays, liver resections must be performed under ultrasound control, since the above-mentioned not only enables to determine the stage of liver cancer, but also proper implementation of treatment.

In France, IOUS during liver resections was introduced by Bismuth in 1984 – he performed subsegmentectomy under ultrasound control. American investigators (Rifkin, Parker and Machi) demonstrated that the IOUS examination leads towards a change in the primary method of treating liver tumors in up to 49% of patients. The above-mentioned was confirmed by studies carried out in European countries. In 1983, Angelini was the first to perform intraoperative ultrasound of the liver in a patient with colorectal cancer. Routine IOUS in patients with colorectal cancer enabled to diagnose metastatic lesions to the liver, which were not preoperatively visible, in 5-10% of cases (4). Additionally, intraoperative liver ultrasound is used in the location of intrahepatic abscesses, as well as cryoablation and thermal ablation of unresectable tumors.

The first intraoperative visualization of the gallbladder concrement by means of B presentation imaging took place in 1979, being performed by Lane and Crocker using a 7 MHz probe. Diagnosis was confirmed by intraoperative cholangiography and biliary duct revision. The above-mentioned authors demonstrated that IOUS has a similar accuracy, shorter duration, and lower incidence of failures, as compared to intraoperative cholangiography. The next step was the use of intraoperative ultrasound for the determination of the biliary ducts in patients subject to laparoscopic cholecystectomy.

The first IOUS examinations of the pancreas were performed by Lane and Sigel in the eighties of the past century. Initial reports emphasized the possibility of determining portal vein infiltration and Wirsung duct dilatation, considering patients with pancreatic cancer. Serio et al. in 1992 showed that IOUS influenced the therapeutic process, considering surgical intervention in 28% of patients. In 1986, Schoenecker used IOUS in patients qualified for intraoperative radiotherapy of pancreatic cancer.

Amongst endocrine tumors intraoperative ultrasound by means of presentation B was used for the first time in the visualization of a

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parathyroid adenoma (Sigel – 1981), insulinoma (Lane and Copland –1982), and gastrinoma (Sigel –1982). The IOUS examination enables to detect very small insulinomas (>3 mm), since the above-mentioned are usually hypoechogenic. Zeiger in 1993, demonstrated that the detection of insulinomas by means of IOUS amounted to 80-100%. Thus, IOUS was considered to be one of the best for the localization of these tumors (4).

In conclusion, the following benefits associated with IOUS were observed in the eighties of the past century:

– novel data influencing intraoperative decisions,
– supplementation or replacement of intraoperative radiological examinations,
– possibility to perform surgical procedures under ultrasound control,
– assessment of the radicalism of the procedure.

Table 3 presented the history of intraoperative ultrasound in relation to its clinical indications.

It was not until the mid-eighties of the past century that in Europe and Japan laparoscopic probes were introduced, enabling B presentation imaging. The above-mentioned technique gained popularity in the nineties of the 20-th century when laparoscopic cholecystectomy became popular. In 1993, Thomson proposed the use of endoluminal (inside the biliary ducts) probes for the diagnostics of choledocholithiasis. These probes did not gain popularity, since convex, sector, and linear probes placed inside the abdominal cavity by means of 10mm trocars were produced. The primary use of laparoscopic cholecystectomy was aimed at evaluating the biliary ducts, considering the presence of concrements, which was first described by Stiegmann in 1994 (4). Several studies demonstrated that the above-mentioned procedure has a similar accuracy, as compared to that of intraoperative cholangiography. Another application of laparoscopic ultrasonography consisted in the more accurate evaluation of advanced tumors during explorative laparoscopy, especially in case of patients with pancreatic, gastric, and biliary ducts cancer. Liu in1995 was the first to use laparoscopic ultrasonography together with Doppler imaging. Modern imaging techniques including the 3D option, contrast agents, and Doppler imaging are becoming more available during intraoperative examinations, and will eventually influence future development of imaging methods. Adequate training of surgeons performing ultrasound examinations is necessary, as so the examination results provide reliable and valuable information. Table 4 presented the first clinical application of laparoscopic ultrasonography.

Breast ultrasound is nowadays the key examination suitable for the assessment of pathological lesions, their preoperative localization, as well as to perform biopsies. In 1952, Wild and Reid published the description of 21 breast tumor ultrasound examinations of which two were the first breast tumors visualized in the B presentation. The first proposal

Table 3. First clinical use of intraoperative ultrasonography

Year	Author	Event
1977	*Cook, Lytton, Makuuchi*	first intraoperative ultrasound imaging in presentation B
1979	*Lane, Crocker*	first intraoperative visualization of biliary duct concrements –presentation B
1980	*Lane, Sigel*	first intraoperative ultrasound of the pancreas
1981	*Sigel*	first intraoperative ultrasound evaluation of a neuroendocrine tumor (parathyroid adenoma)
1984	*Bismuth*	intraoperative ultrasound as a standard in patients subject to liver resection
1983	*Agelini*	first intraoperative evaluation of the liver by means of ultrasound in patients with colorectal cancer
1985	*Takamoto*	first intraoperative ultrasound with the use of color- doppler
1986	*Schoenecker*	intraoperative ultrasound for the imaging of pancreatic cancer in patients subject to intraoperative radiotherapy
1992	*Kasai*	intraoperative evaluation of hepatic and portal venous flow in patients after liver transplantation

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Table 4. First clinical use of laparoscopic ultrasonography

Year	Author	Event
1983	*Ohta, Frank*	prototype probes for B presentation real-time imaging during laparoscopic procedures
1993	*Thomson*	endoluminal probe in the evaluation of biliary ducts
1993	*Murugiah*	evaluation of the stage of pancreatic cancer based on laparoscopic ultrasound
1994	*Stiegman*	laparoscopic ultrasound in the diagnosis of choledocholithiasis
1995	*Bartlett*	laparoscopic ultrasound in the evaluation of the stage of gastric cancer
1995	*Liu*	first laparoscopic ultrasound with the use of the doppler mode
1996	*Mortensen*	laparoscopic ultrasound in combination with endoscopic ultrasonography increases the diagnostic accuracy in patients with gastrointestinal tumors

for the clinical use of breast ultrasound dates back to 1954, being published by Wild and Reid (5). They advocated the use of ultrasonography to differentiate benign and malignant lesions, but not for screening. Le Land in 1969, used a 2.5 MHz probe for breast examinations, which consisted of one crystal, being the source of ultrasound, and 4 crystals as receivers. Le land preoperatively recognized 15 of 16 cases of ductal carcinoma. However, he did not recognize three cases of medullary cancer, where the acoustic shadow is usually not observed. In the sixties of the past century breast ultrasound developed primarily in the United States, Australia, and Japan. The introduction of gray-scale imaging in 1969 proved to be a significant development. Kossoff and Jellins in Australia constructed a breast scanner with a water bath containing a probe, which was lowered to the chest of the examined subject. Kelly-Fry in the United States was the first to perform breast ultrasound examinations in healthy female patients of all ages, in order to detect subclinical pathological conditions (5). In Japan in the fifties and sixties of the past century numerous authors mainly focused on the differentiation of benign and malignant breast lesions. Kasumi and Kobayashi distinguished 23 criteria for the evaluation of breast lesions. Through the use of 5 MHz frequency probes the obtained resolution images reached 2 mm. The introduction of digital technology into ultrasonography in the early eighties of the past century enabled to obtain more precise breast images by beam forming and digital signal processing. In the nineties of the past century the following techniques were developed: harmonic imaging and real-time spatial compounding. Harmonic imaging enabled to eliminate many artifacts associated with the dispersion of the ultrasound beam. Originally, this method was used to improve blood flow imaging after experimental administration of intravenous contrast medium. On the other hand, real-time spatial compounding involves the use of multi-beam ultrasounds running at a different angle, in order to obtain a uniform image.

The first studies on the use of Doppler techniques in the evaluation of breast lesions were conducted by Burns and Wells in England and the previously mentioned Jellins and Kossoff in Australia (5). They demonstrated that arterial vascularization was a common finding, considering malignant tumors. The use of color-Doppler and power-Doppler significantly increased the accuracy of breast ultrasound examinations, however, did not allow to obtain 100% specificity. When in the nineties of the past century manual probes appeared, enabling real-time imaging of the breast parenchyma, the method found application in the monitoring of thin-needle and thick-needle biopsies. In 1990, Fornage described ultrasound-guided biopsy results obtained from patients with breast cancer (volume < $1cm^3$). Nowadays, the BIRADS scale has been developed for the evaluation of breast ultrasound, which allows for a clear definition as how to proceed with the patient, depending on the characteristics of the diagnosed pathology. Table 5 presented the milestones in the development of breast ultrasonography.

Interventional ultrasonography has developed parallely to the progress in diagnostic ultrasound. Holm and Goldberg used presentation B imaging for their biopsies. Rasmussen in 1972, described the use of Holm's probe for the biopsy of liver metastases. He demonstrated that ultrasound-guided biopsies enable to collect samples from the lesion in 85% of cases, while a blind liver biopsy in only 23% (6). Real-time ultrasound imaging was introduced into clinical practice at the turn of the

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Table 5. Development of breast ultrasound

Year	Author	Event
1952	*Wild, Reid*	first image of breast tumor- B presentation
1953	*Howry*	ultrasound evaluation of breast tumors -in vitro
1969	*Le Land*	preoperative ultrasound breast cancer diagnosis
1969	*Kossoff, Jellins*	breast ultrasound scanner with water bath
1972	*Kelly-Fry*	ultrasound in the detection of subclinical breast lesions
1974 1982	*Kobayashi* *Kasumi*	description of the 23 criteria used in the differentiation of benign and malignant breast lesions
1983	*Jellins, Kossoff*	Doppler in the determination of focal breast lesions
1990	*Fornage*	breast tumor biopsy under ultrasound control (<1 cm^3 volume)
1995	*Stavros*	characteristics of benign and malignant breast lesions based on the ultrasound image-750 breast tumors

seventies and eighties of the past century. The first report concerning real-time biopsy was from Japan in 1979 (Saitoh).

Apart from special probes with a biopsy needle canal, many manufacturers began to produce adapter probes enabling to perform ultrasound-guided biopsies. The above-mentioned also enabled to perform biopsies during endosonographic examinations. The introduction of automatic True-Cut needles allowed to perform thick-needle biopsies with the histological assessment of the collected samples. Initially, the above-mentioned needles were used for prostate biopsy in 1987, and in 1989 for the biopsy of other organs (6). The first interventional procedures on the abdominal cavity performed under ultrasound control involved the aspiration of fluid compartments. In 1972, Goldberg and Pollack in Philadelphia performed the first ultrasound-guided paracentesis, while Holm described the percutaneous drainage of an intraabdominal abscess. In addition to the aspiration of the peritoneal fluid, Goldberg and Pollack also performed puncture of 16 kidney cysts under ultrasound control. Hancke and Smith in 1975 used ultrasound for the percutaneous drainage of a pancreatic cyst. Pedersen was the first to describe the drainage of a kidney abscess under ultrasound control in 1973. In 1978, Makuuchi described the first percutaneous cholangiography performed under ultrasound control. In the eighties of the past century ultrasonography was used to perform a number of invasive procedures, such as pericardiocentesis, abscess drainage, nephrostomy, as well as the introduction of catheters into venous and arterial vessels. The significant development of interventional techniques is demonstrated by the fact that during the period between 1975 and 1980 only 63 studies were published concerning the issue, while during the past five years (2007-2011)-5891 publications.

In addition to performing biopsies and the aspiration of fluid compartments, ultrasonography has been used during therapeutic procedures. Solbiati in 1985, described the injection of a 96% solution of alcohol into parathyroid adenomas. Livraghi in 1992, demonstrated that injections of alcohol prolong survival in case of patients with hepatocellular carcinoma. However, he only performed the procedure in case of small lesions (<3 cm). Hans Holm was the pioneer of interventional ultrasonography, as an alternative to surgical treatment of cancer. In 1983, he described the transperineal technique of administering iodine-125 under ultrasound control for the treatment of prostate cancer. Despite promising results many authors withdrew from the use of this method, because of the high incidence of post-radiation proctitis often requiring stoma exteriorization. Two years later (1985), Hashimoto proposed to supply heat to the tumor by means of a laser using needles under ultrasound control. Rauikumar in 1987, described cryotherapy of liver metastases performed under ultrasound control. Originally, cryoablation was performed under ultrasound control during laparotomy. Nowadays, such procedures may be performed percutaneously (6). Table 6 presented the development of interventional ultrasound procedures in the seventies and eighties of the past century.

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Table 6. First clinical use of interventional ultrasound

Year	Author	Event
1972	*Holm*	first probe used in case of biopsy
1972	*Rasmussen*	biopsy of metastatic lesions to the liver under ultrasound control
1973	*Goldberg*	percutaneous drainage of kidney cysts
1974	*Pedersen*	percutaneous cannulation of a renal pelvis under ultrasound control
1975	*Hancke, Smith*	percutaneous drainage of a pancreatic cyst under ultrasound control
1978	*Makuuchi*	first percutaneous cholangiography under ultrasound control
1979	*Saitoh*	first biopsy with the use of real-time imaging ultrasonography
1987	*Rauikumar*	cryotherapy of liver metastases under ultrasound control

Novel imaging techniques and ultrasound procedures

When the position of real-time B presentation ultrasound imaging was established, one observed further development of examination techniques and procedures performed under ultrasound control. Progress initially consisted in the introduction of various Doppler-imaging options, followed by the use of ultrasound contrast agents, sonoelastography, 3D and 4D ultrasound examinations, and such procedures as thermoablation or beam-focused ultrasound for the local induction of necrotic tissues.

Initially, the only available Doppler option was the use of continuous Doppler imaging. In 1966, Baker, Watkins and Reid from Seattle began work on the construction of pulsed-Doppler, which resulted in the creation of the first camera enabling such investigations in 1970 (1). After further improvements in the eighties of the past century pulsed-Doppler was adopted to be used in case of carotid artery examinations. Another discovery was the use of power-Doppler, proposed by JM Rubin in 1994, for the evaluation of vascular blood flow without specifying the direction of the flow (1). The color-Doppler option was the next step in the development of intraoperative ultrasound. Takamoto in 1985 was the first to apply color-Doppler during a cardiosurgical operation. In case of vascular surgery, color-Doppler enabled to determine the areas of vascular reconstruction, not only in the carotid and peripheral arteries, but also in the renal arteries. Kasai in 1992 proposed the use of IOUS and color-Doppler for the evaluation of hepatic and portal venous flow in patients after liver transplantation (4).

Raymond Garmiak from the University of Rochester was the first who pointed to the possibility of using contrast agents in ultrasonography, analysing mitral valve images in the M presentation. The above-mentioned valve was the only heart structure in the sixties of the past century, which was visualized by means of ultrasound (3). By changing the direction of the ultrasound beam he was able to obtain the image of the aortic valve. He performed the ultrasound examination in a patient who was simultaneously subject to cardiac catheterization assessing the cardiac output by means of indocyanine green. Each injection of dye into the heart resulted in an intensive contrast effect (M presentation), which confirmed the location of the aortic valve. The rapid development of contrast enhanced ultrasonography was only possible after obtaining second generation contrast agents consisting of gas micro-vesicles. These agents when the low mechanical index was used allowed to amplify the acoustic signal without damaging the vesicular structure.

Color-coded dynamic sonoelastography is a novel ultrasound imaging technique. Tissue deformation caused by controlled compression of the ultrasound probe was registered and presented in the form of an elastogram, being simultaneously obtained with B presentation images. The red color on the elastogram corresponds to the elastic tissue, green-intermediate tissue, and blue-rigid tissue. Additionally, computer analysis allowed for the quantitative assessment of the fibrosis of investigated tissues. The first devices assessing elastographic evaluation (produced in 1997) enabled static analysis by means of computer signal development obtained before and after tissue compression. The second generation of devices (developed between 2003 – 2007) enabled to perform dynamic elastography with real-time tissue imaging (8).

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The first 3D ultrasound examination was performed by Olaf von Ramm and Stephen Smith from the University of Duke in 1987 (9). The above-mentioned has been mainly used in fetal ultrasound examinations. The 4D option allows to visualize the fetus in three real-time dimensions, without delay, due to computer imaging processing.

In 1990, two independent groups of researchers described the use of radio-frequency ablation of liver lesions. Mc Gahan and Rossi used monopolar needles, which were responsible for the coagulation of liver tissues. Mc Gahan performed thermoablation of primary liver tumors in patients qualified for hepatic resection. Rossi on the other hand, used the above-mentioned method in case of patients diagnosed with hepatocellular carcinoma. Needles were developed enabling the ablation of larger areas, and thermoablation was used in the treatment of liver metastases.

Chapelon (1991) and Yang (1993) proposed the use of high-intensity focused ultrasound (HIFU) to induce local tissue necrosis (6). This method has been used in the treatment of lesions, too which one can directly apply the ultrasound probe, such as in case of liver cancer. Nowadays, interventional ultrasonography has become a routine procedure performed by many physicians of different specialty. In the future, one may expect further development of already existing methods, as well as new interventional procedures performed under ultrasound control.

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Received: 2.04.2012 r.
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- 10.2478/v10035-012-0090-4
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