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Examples of computer-aided combined use of different methods of medical imaging

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This paper is devoted to interesting and difficult problems concerned with interdisciplinary biomedical engineering. The main purpose of the paper is to present rules and application of still developing modern methods of medical imaging combining properties of the selected techniques. The examples considered by the authors include combined applications of different methods of imaging such as: X-ray imaging, videoendoscopy, and ultrasonography. Some selected examples of effects obtained during real interventions assisted by combined imaging of operation site are shown in the paper. Examples of imaging the application of stents allowing for the performance of diagnostic and therapeutic procedures are also reported. Videoendoscopy imaging and X-ray imaging are two complementary methods applied during the interventions presented in stenting control. On the one hand, these methods facilitate a significant increase in diagnostics and treatment comfort. On the other hand, there is possibility to control stenting efficiency.

KEYWORDS: computer-aided systems, biomedical engineering, methods of imaging, stenting control

1. Introduction

The ultrasound waves and different parts of the electromagnetic spectrum have very different effects upon interaction with biological objects [11, 17]. When a biological object is exposed to a given kind of waves, we can receive the selective response to particular wavelengths. The surface conditions, internal structure and size in the direction of input signal action are of great importance. Radiation energy may be transmitted, reflected, absorbed and scattered by living tissues.

In 1895 Wilhelm Conrad Roentgen made the first radiogram of a palm, starting the development of noninvasive image diagnostics methods. Currently, different imaging methods are able to detect different properties of investigated tissues through a variety of phenomena to be utilized [2, 12, 18, 21]. Medical imaging helps physicians to evaluate an area of the human body that is not normally visible. Particular methods differ from the point of view of advantages and disadvantages, range of applications, degree of invasive or noninvasive interaction, patient ballast, and complication of procedures. Effectiveness and precision can especially be improved when some combined methods of the imaging will be used. For example, the optical image resolution can be lower than that of X-ray images; however, it enables to provide information on the functional conditions unavailable in the RTG technique.

Currently, computer-aided diagnosis systems provide an assessment of a disease using image-based information alone or in combination with other relevant diagnostic data and are used by clinicians as a tool in detection and differential diagnosis of abnormalities in medical imaging [3, 20]. Computer creation and analysis of virtual biosignal can be useful to simulate real signals occurring in pathological situations when measurements are impossible because of either ethical or technical limitations. The results may be useful in computer-aided generation of reference data for evaluation of the interaction between tissues and ultrasound- and electromagnetic radiation.

2. Specifity of biomedical engineering

Biomedical engineering is the interdisciplinary, diverse field based in both engineering and the life sciences relating to physiological phenomena as well as to electrical, optical, mechanical, chemical, physical and other principles to be applied in diagnostics and therapy [1, 7, 12]. Biomedical engineering includes such areas as e.g.: bioinstrumentation, biomaterials, biosensors, biotechnology, tissue engineering, and medical imaging. The latter is considered herein. Over the last years, the development of new and improved methods and techniques of imaging is impressive. Advances in the technology are due to the increasing interaction and collaboration between physicians and engineers [4]. Efficient and safe application of ultrasound-tissue and electromagnetic radiation-tissue interactions to biomedical engineering must meet the various human and technical needs such as: medical practice, ethics, clinical care of patients, instrumentation reliability, and material biocompatibility.

3. Methods and techniques used in combined medical imaging

3.1. Advanced X-ray imaging

Because different tissues absorb different amounts of radiation, the X-ray images show the parts of human body in different shades of black and white. Bones look white, soft tissues look gray, and lungs look black. More advanced computed tomography (CT) uses X-ray equipment to make cross-sectional pictures of human body [2, 16]. Special computer programs are used to create 3D reconstruction of a given organ from 2D scanned images (Fig. 1) with the Digital Imaging and Communications in Medicine (DICOM) standard for distributing and viewing any kind of medical image [21]. The newest multislice CT scanners allow more pictures to be imaged in a shorter period of time. Small abnormalities may be detected.

X-rays are a form of harmful ionizing radiation which exposure from CT is higher than that from standard chest X-ray and mammography procedures, but the increase in cancer risk from a typical CT procedure is still small (about 1 in 2,000) [2, 16].

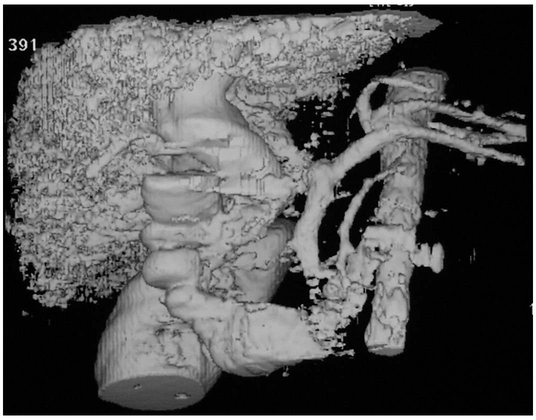

Fig. 1. Example of CT reconstruction of the liver and bile tree

3.2. Ultrasonography

The term "ultrasound" refers to sound wave frequencies > 20,000 Hz that are beyond human hearing. The USG technique is a consequence of an ultrasound-tissue interaction [3, 6, 11]. Absorption, reflection, refraction and scattering are behaviors of sound waves as they propagate through a given medium. Ultrasound frequencies from 1 to 50 MHz have been investigated for clinical use: the higher the frequency, the better the spatial resolution. Physicians have been utilizing conventional ultrasound for diagnostic imaging since the 1970s. Three dimensional imaging has been used since 1985. The advanced 3-D technology provides physicians to see and distinguish currently many details.

USG is utilized in gastroenterology, cardiology, endocrinology, gynecology, and urology. During pregnancy, ultrasound is widely used to view the fetus. Unlike X-rays, ultrasound does not expose a patient to radiation.

The ultrasound machine creates images from the sound waves. Images occur as the result of acoustic beam-tissue interaction by using a rather large emitting head applied through the patient skin and other integument. A conventional head is the ultrasonic transducer, which converts the electric signal to ultrasound and vice versa. The speed of sound is different in different materials and is dependent on the acoustical impedance of the material. Particular tissues have different acoustic impedance. Propagation of the ultrasonic waves in tissues occurs with a velocity equal to about 1540 m/s. Images are constructed from the echo that returned from investigated organs. Ultrasound performs very poorly when there is air between the scan head and the organ of interest. It is necessary to use a proper water-based "ultrasonic gel" as the medium to eliminate the air layer that is existing between the transducer and the patient skin. This gel is applied to bridge the gap and effectively send the ultrasound waves.

Easy to realize and inexpensive transabdominal USG technique is an often routine examination in diseases of abdominal cavity organs. Obtaining an additional surface of human body internal organs is a very valuable USG attribute, however, there are some limitations connected with the conventional percutaneous technique. Overlying gas in the gastrointestinal tract often makes ultrasound scanning difficult. Some important problems occur in such cases, e.g. a significant degree of patient overweight, intestinal gases, and chronic flatulence. Body organs are mostly water. If the propagation path includes fluids, the effects of refraction that changes the path of the ultrasound beam can be significant. Ultrasound has also a trouble penetrating bone. Additionally, the detection of microbubbles is not easy because of the weak signals derived from the bubbles. On the other hand, the USG technique is a contact method that needs to use some pressure, and therefore, a tissue compression has to occur, causing spatial distortion.

The two-dimensional image-acquisition process relies on the assumption that the ultrasound pulse travels in a straight line, and the speed of sound is constant. The typical USG transducers are hand-held heads that are placed directly on the examined area and moved over the patient. When a three-dimensional ultrasound image is being acquired, the transducer is moving continuously [3]. Both the transducer and tissue motion can introduce inaccuracy.

Ultrasound was previously only able to capture a single imaging plane, but today it can acquire volumes. Today, ultrasound images are available with higher resolutions allowing physicians to use ultrasound instead of CT for image-guided biopsies and ablations. Computer-aided detection aids physicians to find the edge of the lesion and analyze it [3].

3.3. Videoendoscopy

The role of optical techniques in current tendency to developing combined medical imaging is especially significant in, e.g., the modern videoendoscopy [8, 13, 18, 19]. The endoscopy deals with the possibility of performing diagnostics and minimally invasive surgery by means of an endoscope. A modern videofiberoscope is a computer-aided endoscopic device equipped with a CCD microcamera of very high resolution situated at the flexible catheter probe tip (Fig. 2a).

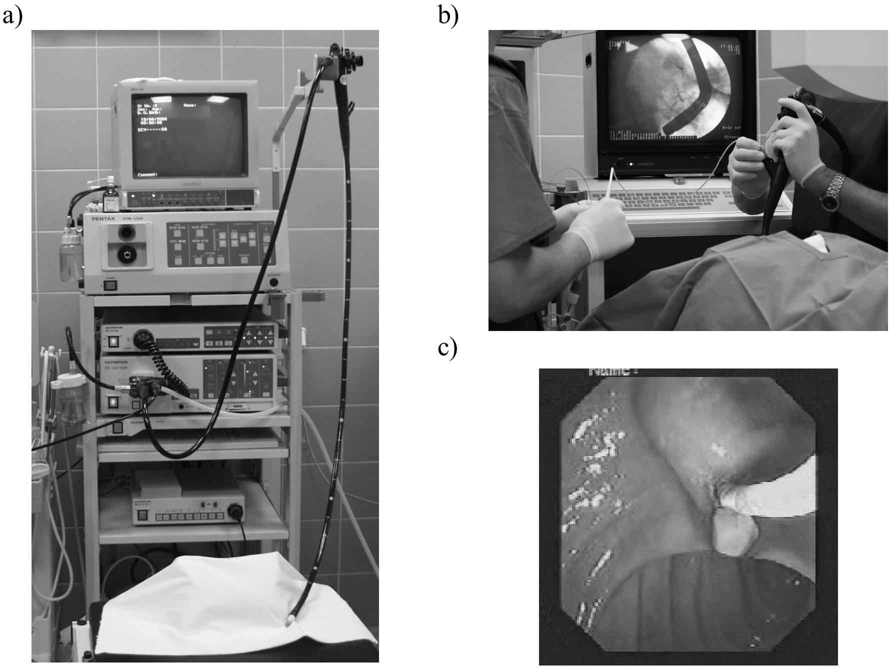

Fig. 2. a) View of a modern videoendoscope, b) example of the minimally invasive fiberoscopy procedures, c) image illustrating a selected step of the endoscopic extraction of a gallstone

This camera allows direct transmitting data to be acquired when light emitted by the xenon source (power 300 W) is delivered from the outside unit to a human body inside. Modern high-performance miniature color CCD video cameras are manufactured for endoscopy in 1.8 mm and 3 mm sizes. Offering excellent image quality, the cameras are suitable as visualization devices for companies that wish to develop their own flexible and rigid videoendoscopes.

Videoendoscopes are equipped with several channels including a fiber optical system for the illumination of an investigated area and transmission of an acquired image as well as a functional channel that makes a possible insertion of proper tools, manipulators, and other accessories (Fig. 2b). External devices can aid these tools as e.g., electro-coagulation knifes, lasers for cauterization, plasma argon coagulators. Figure 2c illustrates one of the steps of the endoscopic extraction of a gallstone.

From the medical application point of view, the advantages of the optical fiber systems include important known attributes such as great flexibility, low loss, and small size, noise avoidance problems. However, applications of the videoendoscopy used as only one imaging method are still limited. First of all, anatomic body structures make a possible moving with fiberoscopes only inside natural tracts of the human organism. Furthermore, current endoscopic probes are not yet able to reach all parts of the small ducts. All units should meet the rigorous demands of endoscopic and other procedures in order to work comfortably and safe [13, 15].

Videoendoscopy makes a possible evaluating attributes of a pathological object only when a detected tissue change grows up into the lumen of the investigated digestive tract. It is impossible to get information about the degree to which this abnormal process has spread beyond the tract wall. Analysis of ultrasonic images may effectively assist applications of optical endoscopic surgery because allow the visualization of the tissue structure beneath the organ surface.

The flat sight of obtained endoscopic images is one basic limitation with a detection of information. Virtual endoscopy, which is based on the modeling of images to be obtained with, e.g., a computer tomography, can be helpful in training, because attributes of investigated objects may be recognized without real procedures [8].

Applications of videoendoscopy used as only one imaging method are still limited. However, acquisition of additional planes of internal organ visualization is possible with X-ray. Simultaneous use of X-rays in different planes allows, e.g., spatial visualization of the endoscopic device and other tool location in relation to operated organs.

3.4. Endoscopic ultrasonography

This method bases on two imaging techniques: videoendoscopy and ultrasonography [5, 9, 14]. Videoendoscopy allows evaluating the growing up of intraluminal pathological lesions. Ultrasound probe on the end of an endoscope or small, rotating probes inserted in its working channel makes the so called "through the wall" images possible. Rotating USG probes enable acquiring vertical to an axis in whole 360 radiuses images. The 5-20 MHz frequency probes are used. The small diameter of probes (2 do 3 mm) makes their deep insertion into bile or pancreatic ducts possible.

In the case of esophagus and stomach cancers, endoscopic ultrasonography may be more reliable than endoscopy as well as computer tomography. Imaging of these organs shows their specific layered structure and enables determining the disease degree. The selected example of the endoscopic ultrasound image presented in Fig. 3b distinguishes layers in structure of the digestive tract. Intervening gases do not compromise images and resolution of examined structures is great.

Combination of both ultrasound and endoscopic techniques in the EUS techniques allows in obtaining new extended areas of deep application. From the point of view of the diagnostic precision, the EUS technique is unique when compared to the conventional USG (Fig. 3a) where disturbances are caused by the examination through an integument. EUS is also less invasive than the intraoperative USG, which is applied during the conventional and laparoscopic surgery.

a) b)

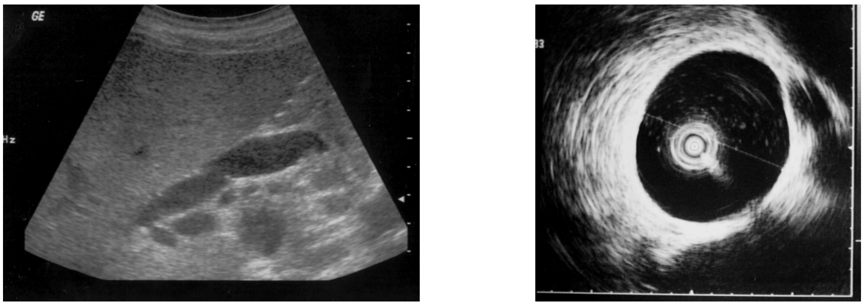

Fig. 3. Two corresponding images of the same enlarging biliary ducts: a) USG image acquired during abdominal examination with a convex transducer (3.5 MHz); b) EUS image observed with a rotating mini-probe (20 MHz)

4. Examples of stenting control with combined imaging

Stenting is the term used in medical interventions for:

- endoluminal placement of self-expanding or balloon expandable metallic prosthesis bioinstrumentation,
- insertion of plastic tubes and catheters for drainage in the duct system.

A stent is the endoprosthesis used to hold tissue in place, to keep an obstructed lumen patent, to drain a tubular or ductal structure in cases of obstruction [10, 13]. Alimentary stents are plastic, metal or silicone tubes designed to make open the obstructed area and help prevent it from becoming obstructed again. Self-expandable metallic stents are cylindrical in shape and are available in a number of diameters and lengths. Unexpanded stents are small enough to fit through the channel of an endoscope. Treatment of benign esophageal strictures consists of esophageal dilation by use of endoscopic stenting.

Modern stents are usually made as coated wallstents. These covered stents carry the advantage of preventing tumors from growing into the stent, although they run the risk of increased migration after deployment.

The self expandable elastic alimentary stents made of shape memory titanium-nickel alloy are biocompatible and very tolerant to erosion. Shape-memory materials are very elastic: when the deforming factor is released a stent can return to its original shape. The risks of the stent placement procedure can cause infection, bleeding, pain, esophagus perforation. There will be also the stent migration when a stent moves out of place. However, all these complications are rare.

Figure 4 shows an example of the set of devices and apparatus used during the alimentary tract interventions under combined imaging. Videoendoscopy supported by X-ray scanning gives the possibility of precise treatment stenting. X-ray imaging can detect such potential complications as tissue perforation and stent misplacement or movement. The stents may be inserted by endoscopy but an X-ray imaging should be also used to control guide insertion and as an adjunct tool to endoscopy.

Fig. 4. View of the operating set consisting of ultrasound, videoendoscopic, and X-ray apparatus used for simultaneous imaging of operated organs

Stenting of alimentary tract with self-expanding stents can be an effective minimally invasive technique in palliative treatment of advanced, inoperable cancers of esophagus, pancreas and biliary ducts. The purpose of the esophagus stenting is often to bridge the obstruction in the esophagus interior (Fig. 5). Simultaneous use of X-rays in different planes allows in the determination of the length and width of stents when inserted into an organism as well as delivering proper contrast medium to obtain images of anatomic structures unattainable for endoscopes (Fig. 6).

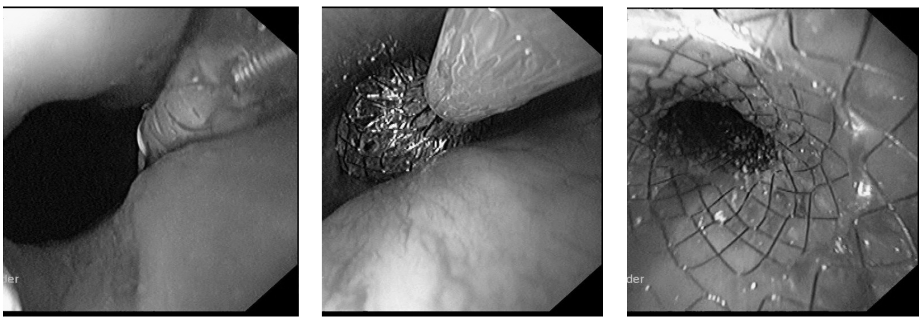

Fig. 5. Three selected images taken during videoendoscopy control of the implanted esophagus stent

a) b)

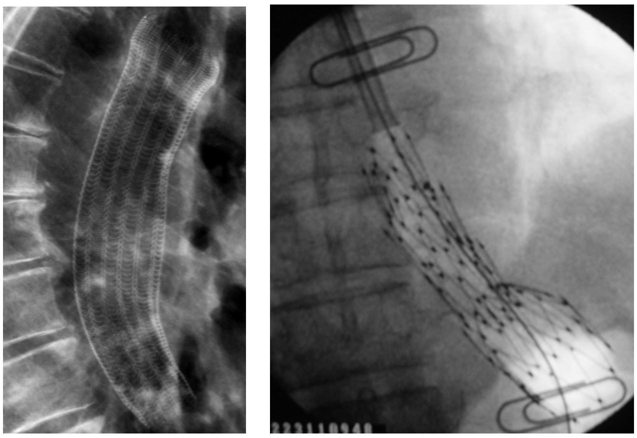

Fig. 6. a) X-ray view of the implanted esophageal stent applied to treat the cancer obstruction by making the ”by-pass” bridging, b) X-ray control of successful application of the state-of-the-art self-expanding esophageal anti-reflux stent (two paper clips were placed only on the patient skin surface to mark an area of the neoplastic infiltration)

5. Conclusion

Modern technology determines the directions in the development of current biomedical engineering, making it possible to spread into areas that were up to now inaccessible. Efficient medical imaging depends on products will must meet the various human and technical needs. There is also necessity to work well in an interdisciplinary team. Moreover, computer methods used for reconstruction process are able to assist the further therapy planning because image sequences can be sometimes difficult to interpret anatomically. Combination of some techniques in combined imaging allows obtaining new extended areas of deep application and facilitates a significant increase in diagnostics and treatment comfort. However, numerous interdisciplinary issues related to these procedures need to be solved and development is required. Progressive development of medical imaging depends on the clinical acceptance of the advanced biomedical technology and engineering. Because image sequences can be difficult to interpret anatomically, the computer methods being used for reconstruction process are able to assist the therapy planning.

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