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Ultrasonic versus radiologic investigation of the paranasal sinuses

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SUMMARY

A comparison between radiography and ultrasound investigation in diagnosing paranasal sinus pathology of 100 patients showed good correlation in 95%. Ultrasound is a non-ionizing alternative especially useful for screening and follow-up studies.

Different diseases of the paranasal sinuses are similar in respect of several of the symptoms they produce. This can make a differential diagnosis difficult (Axelsson and Runze, 1976). In addition, the position of the sinuses in the facial skeleton limits the choice of examination methods. The methods used most often today are radiography and diagnostic antrotomy.

Radiography exposes the patient to undesirable ionizing irradiation and in the last few decades it has been supplemented by other diagnostic methods. Medical ultrasonic techniques developed during the last thirty years are now used routinely in various field of medicine, such as neurology, obstetrics, and cardiology, and in the investigation of abdominal disease.

Ultrasound is mechanical vibrations transmitted in air or in some other medium, i.e. it is fundamentally different from the radiant energy used in radiography. The use of ultrasound can therefore often reveal changes difficult to demonstrate by other diagnostic methods. The risk of undesirable effects of ultrasound is negligible as compared with that of ionizing irradiation. This is an important advantage in the investigation of pregnant women and young children (Hellman et al., 1970; Wells, 1977). For example, Wild and Reid (1952) and Howry and Bliss (1952) applied the ultrasound reflectoscope for diagnostic purposes. In 1954 Edler and Hertz published their first recording of the movements of a mitral valve. Keidel (1947) was the first to recognize the possibility of using ultrasound in the investigation of diseases of the paranasal sinuses. Ultrasound was also described by other authors (Ginsburg, 1961; Kitamura and Kaneko, 1965; Gilbricht and Heidelbach, 1968; Früwald and Till, 1975; Mann et al., 1977; Edel and Issaacson, 1978; Stammberger, 1979; Revonta et al., 1980; Uttenweiler et al., 1980) as a tool in diagnosing diseases of the paranasal sinuses.

THE ULTRASOUND PULSE ECHO METHOD

The principle of ultrasound is applied in medical diagnosis as the ultrasound pulse echo method (Holmer and Lindström, 1978). A transmitter sends out energy in the form of periodic sound pulses with high power but of very short duration. On the boundary between objects with differing sound velocities (v) and densities (δ) (the product $\delta \cdot v = Z$ is the acoustic impedance) some of the energy is reflected back to a receiver. The interval between the outgoing pulse and the returning echo is proportional to the distance from the transducer to the reflecting object. In soft human tissue each microsecond of the interval corresponds to about 0.75 mm.

A block diagram of an ultrasound pulse echo system (reflectoscope) is provided in Figure 1. An interval clock unit triggers a transmitter generating periodic pulses of high ultrasonic power (average power about 10 mW/cm^2) but of short duration. Pulse-repetition frequencies at the "clock" normally appear in the range of 50 to 10 000 Hz. Mostly the transducer is used for both transmitting and receiving and its resonance frequency (f) can be selected between 1 MHz to 10 MHz. The receiver is a wideband amplifier, appropriate for handling the pulses involved since it has a low noise figure and high sensitivity. The echoes received are usually displayed on a cathode ray tube (CRT). Each echo corresponds to a reflecting surface in the human tissue at a certain depth. If individual objects close together are to be resolved, it is necessary to use a short ultrasound pulse. Usually the pulse width is 3 to 5 times the wave length (λ) of the ultrasound frequency. Calculated from $v = f \cdot \lambda$ it corresponds to a few micro-seconds.

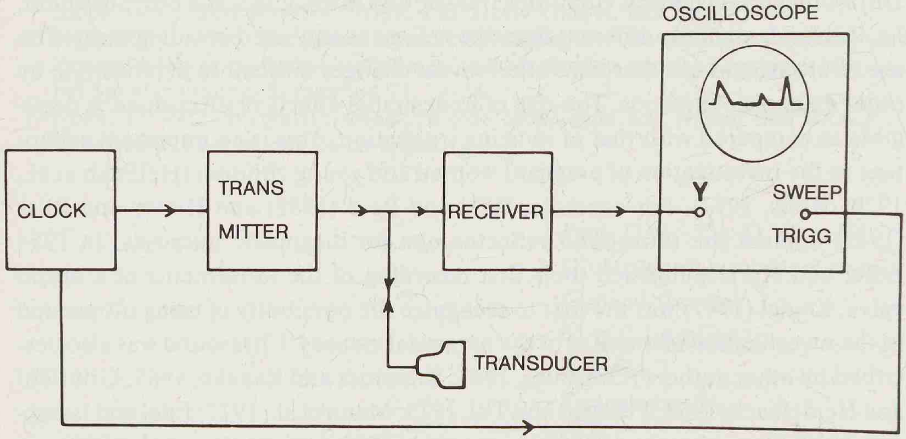

Figure 1. Block diagram of an ultrasound pulse echo system.

Table 1. Reflextion coefficients for boundaries between different media.

	air	water	muscle	fat	blood	bone
air	0	0.99	0.99	0.99	0.99	0.99
water		0	0.0016 ↓ 0.0045	0.035	0.031	0.18 ↓ 0.43
muscle			0	0.10 ↓ 0.16	0.00008 ↓ 0.0013	0.13 ↓ 0.40
fat				0	0.008	0.22 ↓ 0.48
blood					0	0.16 ↓ 0.41
bone						0

PHYSICAL LIMITATIONS

The amplitude of the ultrasonic echo depends on the difference of acoustic impedance on the boundary between the objects. The reflection coefficient is defined (Holmer and Lindström, 1978) and showed different human boundaries (Table 1). This table shows that the boundary between air and any of the tissue involved in medical ultrasonic diagnosis cause total reflection. Another factor affecting the echo amplitude is energy absorption defined as attenuation. Attenuation can be separated into three groups (Holmer and Lindström, 1978):

1. The mechanical energy of the sound wave is converted into heat by internal friction.
2. Scattering of small particles and irregularities in the media.
3. Reflection from boundaries between tissues differing in acoustic impedance.

Factors 1 and 2 involve an exponentially decrease of the ultrasound amplitude as a funtion of both depth and frequency. This is the strongest limitation in the use of high frequency ultrasound.

A small ultrasound beam provides a good resolution of small structures. However, this is not the whole truth since the divegence phenomenon (Wells, 1977) tends to widen the ultrasonic beam and thereby decrease the resolution. A high resolution of a small body requires small tranducers and high frequencies. But since the attenuation of the sound usually increases faster this eliminates the use of higher frequencies (Wells, 1977).

Table 2. Clinical diagnoses before radiographic and ultrasound investigation.

acute maxillary sinusitis	61
upper airway infection	12
acute frontal sinusitis	9
pansinusitis	9
chronic maxillary sinusitis	6
polyposis nasi	3
	100

MATERIAL

For a comparative investigation we have chosen 100 consecutive patients who had conculted our ENT-department because of symptoms referable to the paranasal sinuses. The diagnoses based on clinical examination are given in Table 2. The patients were 5 to 79 years old.

METHODS

All patients were examined with a Picker 80 C ultrasound equipment using the A-scan part and a 2.25 MHz non-focused transducer with a crystal diameter of 13 mm. Between the transducer and the skin a conducting gel ("Aquasonic 100") was applied to secure good airless contact. The sinuses were scanned in different directions for any abnormities. In an air-filled sinus virtually the entire ultrasound is reflected on the boundary between bone and air due to the great difference in acoustic impedance (Figure 2).

Any liquid or solid filling in the sinus allows the passage of the sound which is reflected also from the back wall of the sinus (Figure 3).

In a partly filled sinus it is possible to distinguish between free liquid and a solid mass or a cyst. Tilting of the head backwards makes the free fluid move to the posterior part of the sinus and the frontal part fills with air. The reflection from the back then disappears (Figure 4). A solid mass or a cyst will, of course, not move in this way (Figure 5).

Another way to distinguish between different types of contents, which is especially useful in totally filled sinuses, is to increase the amplification of the reflected signals. Fluid then still produces an echo-free area, while structured (fibrous) masses give multiple echoes, homogeneous tissue echoes only on the boundary while heterogeneous tissue causes echoes from the inside of the structure (Figure 6) (Edell and Isaacson, 1978; Mann, 1979).

In all cases roentgenograms were performed in occipito-mental, occipito-frontal and lateral projections using a horizontal beam. In 37 of the patients the diagnosis was checked with irrigation, sinoscopy or frontal trepanation.

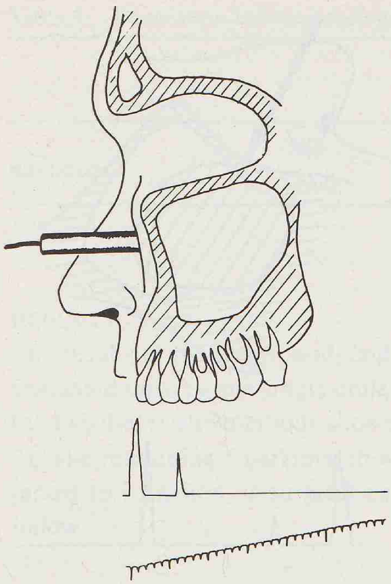

Figure 2. Ultrasonic picture and schematic drawing of an air-filled maxillary sinus. The first peak represents the transmitting pulse and the second peak shows the reflexion bone, mucosa – air.

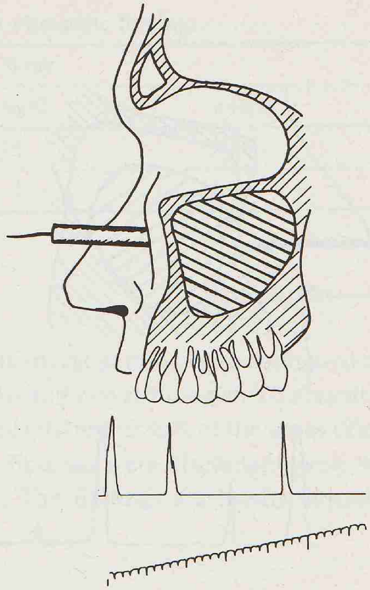

Figure 3. Ultrasonic picture and schematic drawing of a maxillary sinus with fluid. The third peak shows the "back-wall echo".

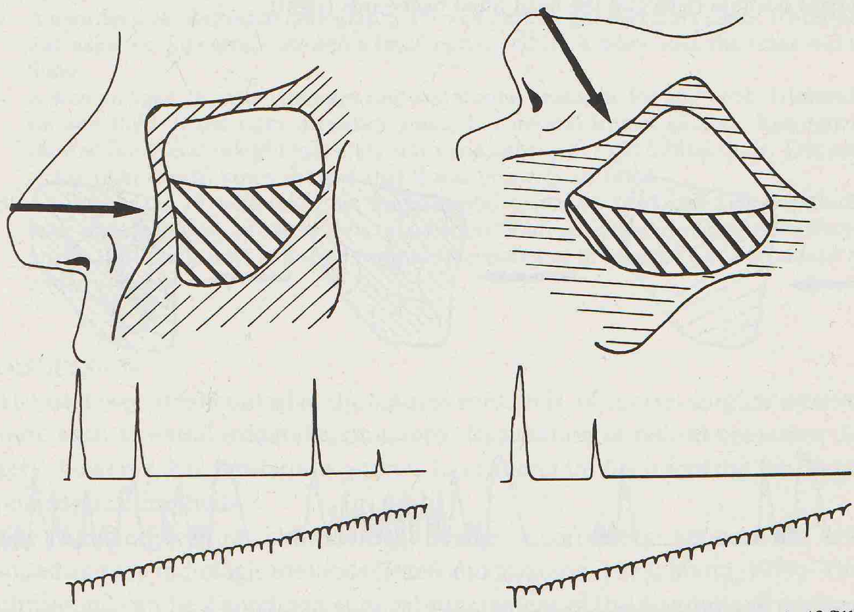

Figure 4. Ultrasonic recordings and schematic drawings of a maxillary sinus half-filled with liquid. Upright position (left) and the head tilted backwards (right).

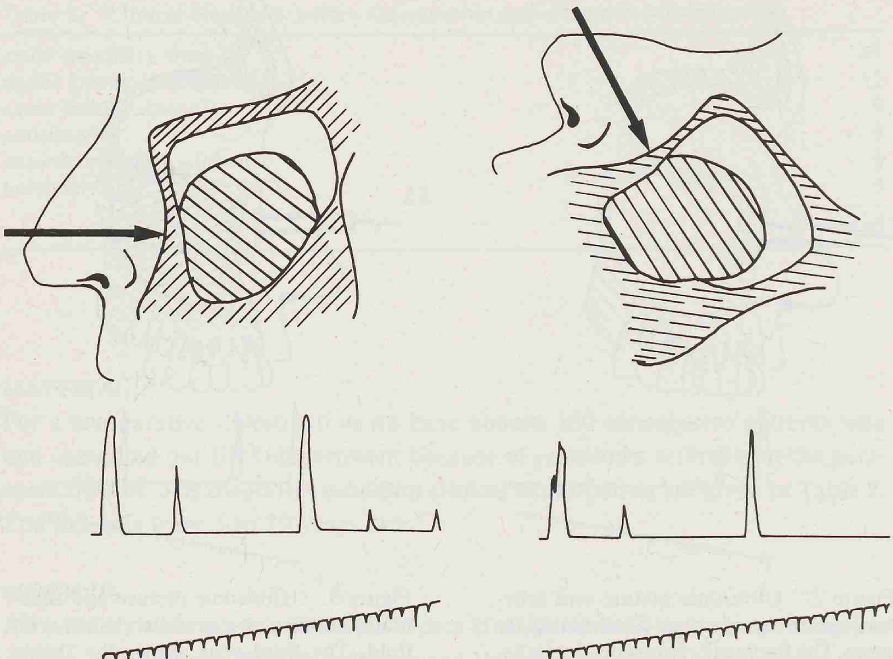

Figure 5. Ultrasonic recordings and schematic drawings of a maxillary sinus with a cyst. Upright position (left) and the head tilted backwards (right).

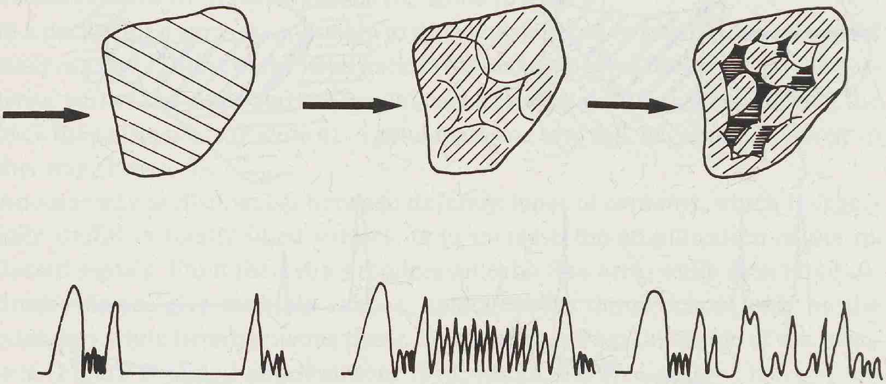

Figure 6. The ultrasonic recording of fluid, homogeneous and heterogeneous tissue when increasing the amplification of the reflected signals.

Table 3. Correlation between radiographic and ultrasonic findings.

		X-ray	
		right	wrong
ultrasound	right	95	3
	wrong	2	0

RESULTS

The results of the ultrasound- and radiologic investigations were compared and evaluated only by one single otolaryngologist and one radiologist. The results of the two diagnostic methods showed good correlation in 95% of the cases (Table 3). The remaining 5 patients, in whom the findings were discordant, were subjected to irrigation or surgical exploration. The findings are briefly described below.

1. A man aged 66, treated for a dental empyema in the right maxillary sinus. Ultrasound was negative, radiography showed a small basal fluid level. Irrigation showed a small amount of purulent secretion.
2. A man aged 46, with symptoms of right maxillary sinusitis for one week. Ultrasound was negative, radiography showed a basal fluid level. Irrigation produced a small amount of mucus.
3. A man aged 38. Repeated radiography showed dense right maxillary sinus. Ultrasound was negative. Sinoscopy showed a small cavity and thick bony wall, the sinus was air-filled.
4. A woman aged 26, with common cold and frontal headache for one week. Ultrasound showed fluid in the right maxillary sinus, but normal frontal sinuses. Radiography showed fluid level in right maxillary sinus and density of right frontal sinus. Trepaning of the right frontal sinus showed that it was properly air-filled.
5. A woman aged 19, with fever and heavy frontal headache. Ultrasound showed fluid in both frontal sinuses and in left maxillary sinus. Radiography showed left maxillary sinusitis, but the frontal appeared normal. Trepaning of the frontal sinus produced pus under pressure.

DISCUSSION

The best way to find out what the sinuses contain is, of course, surgical intervention, such as antral irrigation, sinuscopy, trepanation or radical operation. Surgery, however, has limitations and we have therefore been looking for reliable non-surgical methods.

The comparative study shows a high degree of correlation between the ultrasound and the radiologic methods (Edell and Isaacson, 1978; Mann, 1979). Thus, ultrasound can be a good non-surgical supplement in the diagnosis of paranasal sinus diseases especially maxillary and frontal sinuses.

The *advantages* of ultrasound is the possibility which it offers to distinguish between free fluid and a cyst in a partly filled sinus and to suggest the nature of the substance in a completely filled sinus (Mann, 1979). In the case of hypoplastic sinuses ultrasound may even provide better information than radiography, i.e. in evaluating if a small frontal sinus contains fluid. Furthermore, the technique is easy to learn; it is also quick and can easily be used by the clinician himself without depending on a radiologic department. The method is time-saving and the cost of a suitable A-scan equipment is low. An ultrasound investigation costs only one tenth of that of a proper radiological examination. Ultrasound is non-ionizing and, as far as we know, harmless to living tissue (Wells, 1977). Ultrasound examination can therefore be repeated several times whithout harming the patient, whereas an ordinary radiological examination with 3 films normally gives the lenses a radiation of about 0.45 rad.
A *disadvantage* of the ultrasound is that it does not reveal small marginal mucosal swellings of less than 5-6 mm or small basal changes (Stammberger, 1979), but the clinical importance of such changes is doubtful. Furthermore, investigation of the ethmoid cells and the sphenoid sinus is difficult but these cavities are rarely involved unless there are coexisting maxillary or frontal sinus changes. As ultrasound examination provides no information about anatomy or potential bone destruction it cannot replace the radiographic examination, but is useful as a screening as well as a follow-up method especially in cases of sinusitis. This would need an A-scan equipment designed specially for this purpose. A prototype of such an equipment is already in use (Jannert et al., 1981).

ZUSAMMENFASSUNG

Ein Vergleich zwischen Röntgen- und Utraschalluntersuchung bei 100 Personen mit Verdacht auf patologischen Nebenhöhlenbefund erwies eine gute Übereinstimmung bei mehr als 95% der Fälle. Ultraschall ist eine nicht ionisierende Untersuchungsmethode die besonders für Reihen- und Kontrolluntersuchungen der Sinuspatienten geeignet ist.

REFERENCES

1. Axelsson, A. and Runze, U., 1976: Symptoms and signs of acute maxillary sinusitis. ORL 38, 298.
2. Edell, S. L. and Isaacson, S., 1978: A-mode ultrasound evaluation of the maxillary sinus. Otolaryngol. Clin. North. Am. 11, 531.
3. Edler, I. and Hertz, C. H., 1954: The use of ultrasonic reflectoscope for the continuous recording of movements of heart walls. Kungl. Fysiografiska Sällskapets i Lund Förhandlingar Bd. 24, No. 5, pp. 1-19.
4. Frühwald, H. and Till, P., 1975: Die Echographie bei Nebenhöhlenerkrankungen. Laryngol. Rhinol. Otol. 54, 865-870.
5. Gilbricht, E. and Heidelbach, J. G., 1968: Ultraschalldiagnostik in der Medizin und ihre Anwendungsmöglichkeiten im HNO-Bereich. Z. Laryngol. Rhinol. 47, 737.
6. Ginsburg, M. M., 1961: Zur Frage der Anwendung des Ultraschalls für die Diagnostik einiger Erkrankungen der Mundhöhle under der Oberkieferhöhle. Stomatologija (Moscow) 40, 31.

7. Hellman, L. M., Duffus, G. M., Donald, J. and Sundin, B., 1970: Safety of diagnostic ultrasound in obstetrics. Lancet 1, 1133.
8. Holmer, N. G. and Lindström, K., 1978: New Methods in Medical Ultrasound. LUTEDX/(TEEM-1001)/1-420/(1978) Lund. Thesis.
9. Howry, D. H. and Bliss, W. R., 1952: Ultrasonic visualization of soft tissue structures of the body. J. Lab. Clin. Med. 40, 579.
10. Jannert, M., Friis, S., Andréasson, L. and Holmer, N.-G., 1981: SINUS DIAGNOSIS - A comparison of results obtained by ultrasound, X-RAYS and antrostomy. In Proceedings of the International SYMPOSIUM on Sinusitis, Jersey, May 6-8, 1981.
11. Keidel, W. D., 1947: Über die Verwendung des U S in der klin. Diagnostik. Artzl. Forsch., Z. Forschungsergebn. ges. Med. 1, 349.
12. Kitamura, T. and Kaneko, T., 1965: Le diagnostic des affections du sinus maxillaire par ultra-sons impulsifs. Ann. Otol. Laryngol. (Paris) 82, 711.
13. Mann, W., 1979: Diagnostic ultrasonography in paranasal sinus disease - a 5-year review. ORL 41, 168.
14. Mann, W., Beck, C. and Apostolidis, T., 1977: Liability of ultrasound in maxillary sinus disease. Arch Otorhinolaryngol. 215, 67.
15. Revonta, M., Suonpää, J. and Meurman, O. H., 1980: Die Verlaufskontrolle des Heilungsprozesses der kindlichen Kieferhöhlenentzündung mit der Ultraschalldiagnostik. HNO 28, 91-96.
16. Stammberger, H., 1979: Die Ultraschalldiagnostik des Nasennebenhölen - Möglichkeiten und spezielle Problematiek. Laryngol. Rhinol. Otol. 58, 778-782.
17. Uttenweiler, V., Fernholz, H. J. and Stange, G., 1980: Die Anwendung von Ultraschall in der Nasennebenhöhlendiagnostik. Laryngol. Rhinol. Otol. 59, 773-781.
18. Wells, P. N. T., 1977: Biomedical Ultrasonics. Academic Press, London.
19. Wild, J. J. and Reid, J. M., 1952: Application of echo-ranging techniques to the determination of structure of biological tissues. Science 115, 226.

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