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Phase-inversion tissue harmonic imaging compared with conventional B-mode ultrasound in the evaluation of pancreatic lesions

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Abstract The aim of this study was to compare the diagnostic sensitivity, specificity, and image quality of conventional B-mode US (BM) and phase-inversion tissue harmonic imaging (PTHI) regarding pancreatic pathology. In a prospective study, 107 patients, aged between 28 and 85 years, underwent US examinations of the pancreas with both BM and PTHI in a randomly chosen order. As diagnostic reference, either contrast-enhanced CT or MRI examinations of the upper abdomen were obtained in all patients. Sensitivity and specificity were evaluated using the Student's *t* test. Differences in overall image quality, lesion conspicuity, fluid–solid differentiation, and delineation of the pancreatic tail were analyzed using Wilcoxon's signed ranks test and Bowker's symmetry test. Sixteen of 107 examined patients (15%) were non-diagnostic and excluded due to technical limitations such as abdominal gas. A total of 60 pancreatic lesions (cysts, acute pancreatitis, dilatation of the pancreatic duct, calcifications, and solid tumors) were diagnosed by CT or MRI. Phase-inversion tissue harmonic imaging had a higher sensitivity of 70% (14 of 20) than BM (60%; 24 of 40) for the detection of pancreatic lesions; however, the difference was not statistically significant (p=0.46). In the assessment of lesions <1 cm of size, PTHI had a sensitivity of 70% and BM 46.7%, whereby the difference again was not statistically significant. Phase-inversion tissue harmonic imaging proved to be superior to BM regarding overall image quality (p<0.0001), lesion conspicuity (p=0.0045), and fluid–solid differentiation (p=0.0002), as well as the delineation of the pancreatic tail (p<0.0001). These differences were statistically significant. The statistically significant improvement of image quality with regards to lesion conspicuity, fluid–solid differentiation, and delineation of the pancreatic tail favors the use of PTHI when evaluating the pancreas with US. Sensitivity for pancreatic lesions is increased with PTHI in comparison with conventional sonography (BM), especially in lesions <1 cm in diameter, although the difference was not statistically significant.

Keywords Ultrasonography · Harmonic imaging · Pancreas · Pancreatic carcinoma · Pancreatitis

Introduction

In suspected pancreatic pathology, especially in inflammatory and tumorous lesions, diagnostic imaging plays a crucial role. Ultrasound is often the initial modality for imaging the pancreas as it is inexpensive, easy to perform, and widely available.

Tissue harmonic imaging (THI) is a US technique based on non-linear distortion of the US beam, which has meanwhile been implemented in many US scanners.

Tissue harmonic imaging uses harmonic overtones which are whole-numbered multiples of the fundamental frequencies that are transmitted by US probes. These overtones originate from non-linear propagation of the fundamental frequencies through biological tissue. The principles of nonlinear distortion were already discussed in the early 1980s [1, 2], and 5 years later the first observations of non-linear distortion in tissue were reported by Starritt et al. [3, 4] who examined human calf muscle in vivo using a clinical pulse-echo scanner, and an excised bovine liver in vitro using a focused transducer commonly used in commercial US systems.

In THI the emitted harmonic frequencies are used for imaging, whereas fundamental B-mode US (BM) utilizes echoes of the fundamental frequencies [5]. First developed as a technique for detecting the nonlinear vibrations of microbubble contrast agents [6], harmonic imaging can also be used to image tissue by exploiting the phenomenon of non-linear distortion. Two methods have been developed for the generation of harmonic images, namely harmonic band filtering and phase inversion. Theoretical advantages of THI are better lateral and axial resolution, enhanced signal-to-noise ratio (SNR), and reduced artifacts because harmonic frequencies originate in the human body and pass the body wall only once; moreover, the harmonic beam does not form in the subcutaneous tissue, where a substantial portion becomes distorted. The largest harmonic portion forms close to the focal zone. In THI the signal of the main lobe is relatively higher than the signals of the side lobes and the reverberations when compared with BM.

In previous studies THI and phase-inversion tissue harmonic imaging (PTHI), respectively, have proven to be superior in the US of the heart, the vascular system, the liver, the biliary system, the kidneys, and the female pelvis [7, 8, 9, 10, 11], because harmonic imaging modes show a superior image quality, fewer artifacts, and better delineation of normal and pathological structures compared with BM.

Especially using the filtering technique, several authors observed that the image impression was altered in THI with hard, partly blurring contrast between anatomic structures [10, 11, 12, 13, 14]. They described problems in analyzing the internal details of especially solid lesions and organs. Using the phase-inversion technique some authors found that the deficiencies in dynamic range could partly be overcome [15, 16]. This seems to be caused by the alternative approach of phase inversion [17]. Two sequential pulses are used, usually directed along exactly the same path. The second pulse is phase reversed. The reflected signal following the first pulse is stored electronically and added to that from the second pulse. Their summation results in the removal of the fundamental component, f_0, leaving the harmonic portion of the echoes. This portion contains frequency components at the even harmonics of the fundamental, $2f_0$, $4f_0$, $6f_0$, etc., and lacks all the odd harmonics; thus, no filtering of the frequency band has to take place in PTHI resulting in a wider frequency range available for image formation.

At present, there is no systematic prospective study comparing BM to PTHI in the diagnosis of pancreatic lesions under real-time conditions. In our study we prospectively compared the two modalities regarding sensitivity and specificity. Furthermore, overall image quality, lesion conspicuity, fluid–solid differentiation, and the delineation of the pancreatic tail were evaluated retrospectively to characterize possible reasons for the differences in the diagnostic performance of both modalities.

Materials and methods

Between February 2001 and September 2001, a total of 107 (36 women and 71 men) consecutive patients with suspected pathologies of the pancreas, aged between 28 and 85 years, underwent US examinations.

All patients received contrast-enhanced CT or MRI examinations of the upper abdomen for different clinical indications. The CT or MRI diagnoses were reference diagnoses.

For the CT examinations (Somatom Plus 4, Siemens, Erlangen, Germany) a two-phase protocol (arterial- and portal-venous phase) with a reconstructed slice thickness of 1.25 mm was used. The MRI examinations were performed on 1.5-T scanner (ACS-NT, Philips, Eindhoven, The Netherlands) with the following sequences: axial T2-weighted turbo spin echo; axial 2D-balanced fast-field echo (FFE); and axial dynamic T1-weighted FFE.

To avoid a bias by orally administered CT or MRI contrast medium, the US examinations were either done prior to the CT or MRI scan, or on the subsequent day. No US scan was undertaken on the same day as the CT or the MRI, respectively. In lesions where histopathological reports were available, i.e., when biopsy or operation was performed, the diagnosis of the imaging modalities were correlated.

Informed consent was obtained from all patients according to rules of the ethics committee of our institution.

Sonographic technique, evaluation, and statistics

Each patient was examined by one of two radiologists experienced in US. The examiner performed a scan with both modalities, BM and PTHI, in a randomly chosen order with all patients in supine position. For the US examinations, the patients were either fasted or not specifically prepared, i.e., in emergency situations. For statistical analysis, it was determined whether or not BM or PTHI was used as the first US modality for scanning a patient. The examiner had neither knowledge of the diagnoses nor any clinical data. A Siemens Sonoline Elegra US scanner (Siemens, Erlangen, Germany) was used with a 3.5-MHz curved-array US probe with a frequency of 3.4 MHz for BM and a frequency combination of 2.0/4.0 MHz for PTHI. Imaging parameters were standardized, and only gain and focal depth could be adjusted. The pancreatic lesions were documented regarding localization, size, and sonographic diagnosis. For each modality we sonographically classified lesions utilizing generally accepted criteria [18, 19, 20]. The pancreatic tail was examined using a transabdominal and transsplenic approach. The US diagnoses were compared with the diagnostic reference (CT or MRI) to calculate the sensitivity and specificity of the US modalities. Furthermore, the sensitivity and specificity of both techniques were correlated to the size of the lesions which were classified into lesions below 1 cm, 1–3 cm, and >3 cm in size.

Two radiologists, who had not performed the US examinations, evaluated image quality retrospectively. The radiologists reviewed hardcopies that were blinded for imaging modality and patient data. The US images of the same patient, performed with PTHI and BM, were evaluated separately on subsequent days.

Using three-point grading schemes the image quality was classified as poor, good, or excellent regarding the following criteria: (a) overall image quality; (b) lesion conspicuity as a measure of contrast between anatomical and pathological structures; (c) fluid–solid differentiation within the lesion, and (d) delineation of the pancreatic tail. To have a measure for more distant structures, only ventral transabdominal scans were taken into account in the evaluation for the delineation of the pancreatic tail.

For the statistical analysis, in each patient the average values for overall image quality, lesion conspicuity, fluid–solid differentiation, and delineation of the pancreatic tail with BM and PTHI were compared with each other using the Wilcoxon signed-ranks test. The p values were calculated with a significance level of 0.05. Additionally, the distribution of the ratings for each criterion of image quality was analyzed using the symmetry test of Bowker, which is a McNemar test not restricted to fourfold or 2×2 table data analysis. Probabilities (p values) were calculated with a significance level of 0.05. For the calculation of sensitivity and specificity, the Student's t test was used with a significance level of 0.05. A possible association between the image quality and the body mass index (BMI) was tested calculating the Pearson correlation coefficient at a significance level of 0.05.

Results

Due to overlaying gas, 16 of the 107 patients had to be excluded. Altogether, 91 patients (33 women, 58 men) with a mean age of 62.2±11.9 years (age range 28–85 years) were included in the study. The mean BMI, which is the quotient of the body mass in kilograms and the square of height in meters, was 25.2±4.54 (range 13.5–48).

In 36 patients CT or MRI found a total of 60 pancreatic lesions with a mean diameter of 16.6±16.4 mm (2–60 mm). Nineteen solid tumors (11 head carcinomas, 2 corpus carcinomas, 1 carcinoma of the uncinate process, 2 carcinomas of the pancreatic tail, 1 carcinoid, 1 metastasis of a leiomyosarcoma, and 1 macrocystic adenoma), 17 dilated pancreatic ducts, 13 simple cystic lesions, 6 times an acute pancreatitis, 2 calcifications, 2 complicated cysts (1 echinoccocus, 1 cystic carcinoma), and 1 scar after resection of the pancreatic head were diagnosed. Fourteen of the 60 pancreatic lesions (23%) were limited to the pancreatic tail (7 cystic lesions, 2 calcifications, 2 carcinomas, 2 inflammatory processes, and 1 dilatation of the duct limited to the pancreatic tail). Fifty-five patients did not have any abnormality on CT or MRI.

Table 2 Sensitivities for BM and PTHI as first scanning modality in relation to the lesion size

	BM	PTHI	p value
Lesions <1 cm	7 of 15 (46.7)	7 of 10 (70)	0.27
Lesion 1–3 cm	13 of 20 (65)	5 of 8 (62.5)	0.91
Lesions >3 cm	4 of 5 (80)	2 of 2 (100)	–

Numbers in parentheses are percentages

BM and PTHI as first scanning modality

To assess sensitivity and specificity of both modalities independently without influencing the subsequent modality by the previous one, we compared PTHI and BM as first scanning modality (Table 1). When PTHI was used before BM, 14 of 20 lesions (sensitivity 70%) were detected. With BM as first scanning modality, 24 of 40 lesions were detected (sensitivity 60%). These differences between PTHI and BM were not statistically significant (p=0.46). In the group of lesions smaller than 1 cm PTHI had a sensitivity of 70% compared with BM (46.7%), although the difference was not statistically significant (p=0.27) either. Both modalities showed the lesions >1 cm with similar sensitivities (Table 2).

First-modality BM and second-modality PTHI

With PTHI as second modality the sensitivity was higher (77.5%, 31 of 40) than with BM as first mode (60%, 24 of 40). The difference was not statistically significant (p=0.12; Table 1).

Phase-inversion tissue harmonic imaging as second modality discovered four additional focal processes which were not seen with BM; among these were 1 pancreatic carcinoma, 1 uncomplicated cyst, and 2 dilated pancreatic ducts. With BM as the first US modality, no lesion was found that could not be seen with PTHI.

First-modality PTHI and second-modality BM

Phase-inversion tissue harmonic imaging as first US modality had the same sensitivity (70%, 14 of 20) as BM used as second mode (70%, 14 of 20).

Table 1 Sensitivities and specificities of B-mode (BM) US and phase-inversion tissue harmonic imaging (PTHI) when the modalities were used as first and second US mode in the same patients

	BM first modality	BM second modality	PTHI first modality	PTHI second modality
Sensitivity	24 of 40 (60)	14 of 20 (70)	14 of 20 (70)	31 of40 (77.5)
Specificity	31 of 32 (96.8)	22 of 23 (95.6)	21 of 23 (91.3)	31 of 32 (96.8)

Numbers in parentheses are percentages

Table 3 Grading by two reviewers for overall image quality, lesion conspicuity, fluid–solid differentiation, and delineation of the pancreatic tail

		Reviewer 1					Reviewer 2			
Overall image quality										
		PTHI					PTHI			
		1	2	3	Total		1	2	3	Total
BM	1	6	15	4	25	1	7	16	2	25
	2	3	26	14	43	2	4	27	19	50
	3	0	2	10	12	3	0	1	3	4
Total		9	43	28	80		11	44	24	79
$p<0.0001$[a]							$p<0.0001$[a]			
Lesion conspicuity										
		PTHI					PTHI			
		1	2	3	Total		1	2	3	Total
BM	1	1	4	2	7	1	0	3	2	5
	2	1	9	4	14	2	1	7	6	14
	3	0	2	3	5	3	0	1	5	6
Total		2	15	9	26		1	11	13	25
$p=0.22$[a]							$p=0.087$[a]			
Fluid–solid differentiation										
		PTHI					PTHI			
		1	2	3	Total		1	2	3	Total
BM	1	1	3	1	5	1	2	3	0	5
	2	0	11	7	18	2	0	6	7	13
	3	0	0	3	3	3	0	3	4	7
Total		1	14	11	26		2	12	11	25
$p=0.012$[a]							$p=0.204$[a]			
Pancreatic tail										
		PTHI					PTHI			
		1	2	3	Total		1	2	3	Total
BM	1	25	27	1	53	1	18	24	2	44
	2	8	11	5	24	2	9	17	5	31
	3	0	2	0	2	3	0	0	3	3
Total		33	40	6	79		27	41	10	78
$p=0.009$[a]							$p=0.003$[a]			

[a] p value for Bowker's symmetry test: 1=poor; 2=good; and 3=excellent

With PTHI, the sonographers discovered one dilated duct that could not be found with BM afterwards. Phase-inversion tissue harmonic imaging falsely detected one dilated duct which was neither confirmed by BM nor by CT.

Lesions of the pancreatic tail

Phase-inversion tissue harmonic imaging detected 80% (4 of 5) of the pancreatic tail lesions when used as first scanning modality, whereas BM revealed only 33% (3 of 9). The difference was not statistically significant ($p=0.11$).

In summary, a total of 11 lesions with a mean diameter of 11.2±9.6 mm (range 2–30 mm) were not seen by either modality (5 head carcinomas, 2 tail calcifications, 2 tail cysts, or 2 dilated ducts). Four of these lesions (36%, 4 of 11) were limited to the pancreatic tail.

Specificity

B-mode US, as well as PTHI, showed a high specificity. Used as the first modality, BM identified 31 of 32 inconspicuous pancreases (specificity 96.8%). Phase-inversion tissue harmonic imaging, used as the first modality, had a specificity of 91.3% as 21 of 23 patients with a normal pancreas were correctly identified. The difference was not statistically significant using a 95% confidence interval.

Image quality

Table 3 summarizes the ratings for the image quality. Overall image quality, lesion visibility, fluid–solid differentiation, and delineation of the pancreatic tail were more often excellent or good in PTHI with BM being poor than vice versa. Results were more frequently ex-

Table 4 Mean value (x) and standard deviation (σ) of average values for overall image quality, lesion conspicuity, fluid–solid differentiation, and delineation of the pancreatic tail

	BM	PTHI	*p* value[a]
Overall image quality	x=1.774 σ=0.522	x=2.201 σ=0.549	<0.0001
Lesion conspicuity	x=2.000 σ=0.519	x=2.370 σ=0.492	0.0045
Fluid–solid differentiation	x=1.981 σ=0.528	x=2.389 σ=0.424	0.0002
Delineation of pancreatic tail	x=1.401 σ=0.443	x=1.710 σ=0.580	<0.0001

[a] *p* value for Wilcoxon's signed-ranks symmetry test: 1=poor; 2=good; and 3=excellent

cellent in PTHI with only good ratings for BM than vice versa. Overall image quality of PTHI was rarely rated as being poor while BM was poor in a considerable number of examinations. Both radiologists showed the same tendency for higher ratings of PTHI with statistical significance in the symmetry test of Bowker (Table 3). The average values for the image quality showed a statistically significant advantage for PTHI in all four categories (Table 4).

For the association between the overall image quality and the BMI, a Pearson correlation coefficient of r=–0.19 was calculated, which means that no correlation could be found.

Discussion

Ultrasonography is often the first imaging modality in patients with suspected pancreatic abnormalities who present with abdominal pain, pathologic laboratory findings, or jaundice. Furthermore, the detection of pancreatic abnormalities in asymptomatic patients is important, as the early diagnosis of pancreatic malignancy can be crucial for the prognosis of these patients [18]. On the other hand, it is important to assess the pancreas with high specificity to avoid unnecessary further diagnostic work-up. Twenty years previously, the pancreas was hardly visible, and most of the pancreatic tumors could only be diagnosed indirectly by a hugely dilated pancreatic duct [21]. Endoscopic retrograde cholangiopancreatography (ERCP) was the reference imaging modality for pancreatic carcinomas. Since then, US scanners have continuously been improved. Presently, state-of-the-art scanners enable excellent results in the evaluation of pancreatic tissue in the hands of a highly skilled operator.

Previous clinical studies comparing THI with BM concentrated on criteria of image quality. In most of these studies hardcopies were retrospectively reviewed for lesion conspicuity and diagnostic confidence in focal pathology [7, 8, 13, 15]. There have been few reports which directly compared sensitivity and accuracy of classification of THI with BM. For focal pathology of the liver, Tanaka et al. [12] showed that THI was significantly better in detecting focal masses of the liver. In that study the correct characterization of a lesion was also more often achieved with THI than with BM, especially for hepatocellular carcinoma in cirrhotic parenchyma. Besides better image quality, Hann et al. [8] also found that THI added relevant diagnostic data in 14 of 48 patients examined for liver disease.

In the present work patients were prospectively examined under real-time imaging conditions. The scan order of BM and PTHI was randomly chosen; thus, we acquired independent data for sensitivity and specificity for PTHI and BM, respectively. We found that PTHI shows a higher sensitivity than BM regarding the detection of pancreatic lesion (Table 1), although the differences were not statistically significant. Our figures are in accordance with the literature where sensitivities between 47 and 92% for the detection of pancreatic lesions are reported [21, 22]; however, the sensitivity for the detection of focal pancreatic processes depends on lesion size and location. Venu et al. found a low sensitivity for lesions smaller than 1 cm in diameter (47.7%), whereas sensitivity was 82.6% for lesions between 1 and 3 cm and excellent with a sensitivity of 91.4% for processes larger than 3 cm [23]. In our study, PTHI still had a high sensitivity of approximately 70% for lesions up to 1 cm in diameter, whereas BM achieved only a sensitivity of 46.7%. The difference was not statistically significant, however (Table 2). A limitation of the study might be the relatively small number of lesions, especially of lesions up to 1 cm, considering the fact that the difference in sensitivity was almost exclusively due to differences in small lesions.

We found a high specificity of 91.3% for PTHI and 96.8% for BM, which is in good accordance with the literature which reports specificities between 94 and 100% [21, 22].

By evaluating criteria for image quality we tried to find reasons for the superiority PTHI seems to provide in terms of detection and characterization of pancreatic pathology. The overall image quality and hence diagnostic value of PTHI was better than with BM (Table 4). This seems to result from less degradation of the main US beam before it reaches the region of interest and of less side lobe echoes that interfere with the echoes of the main US beam [10]. Consequently, SNR is enhanced and scattering artifacts are reduced, resulting in a better contrast. We also noticed these effects as the delineation of the pancreas with typical sonomorphological features was often better with PTHI than with BM.

As patients were scanned, either fasted or in an emergency situation, they were not specifically prepared for

the US examination; hence, we had a relatively high rate of non-diagnostic examinations. Sixteen of 107 Patients (15%) had to be excluded mostly because of overlaying gas due to an adynamic ileus, which is a frequent finding in patients with an acute abdomen. The rate of non-diagnostic sonographies can be reduced if the patient is well prepared, that means fasted patients or even better a fluid-filled stomach. In a group of patients who were prepared for ERCP, Gebel et al. [21] reported only 1.3% non-diagnostic sonographies. Interestingly, there was no correlation between the BMI and the image quality, so that obese patients are not necessarily synonymous with limited diagnostic value. A possible explanation for the missing correlation might be the small number of overweight patients (only three patients with BMI greater than 35); however, our subjective impression was that PTHI offered substantial advantages in some obese patients up to a certain BMI. As in previous studies, very obese patients were not suitable for PTHI because of reduced penetration [24].

One theoretical advantage of PTHI is that fluid structures, like cysts, the pancreatic duct, or peripancreatic fluid collections, can be imaged more often anechoic due to reduced reverberation artifacts [25]. As a consequence, internal solid components of lesions can also be diagnosed with more confidence because their echoes do not overlap with reverberation artifacts of fluid-filled cystic structures (Fig. 1). In the present study, this was reflected by better ratings for PTHI concerning fluid–solid differentiation within detected lesions (Table 4). A higher sensitivity for smaller lesions could also be a result of better fluid–solid differentiation as many of the smaller lesions were fluid collections or dilated pancreatic ducts.

Two methods have been developed for the generation of harmonic images: harmonic band filtering and phase inversion. The most obvious method for extracting harmonic components is to apply a high-pass filter to the received signal [26, 27, 28]. This technique leads to a compromise between loss of harmonic signal and contamination from the fundamental frequencies, which causes degradation of low harmonics by high fundamentals resulting in a lower SNR. To minimize this problem, the fundamental band is narrowed by lengthening the pulse, which in turn results in a degradation of axial resolution [29]. Using the filtering technique, several authors discussed that the image impression was altered in THI with hard, partly blurring contrast between anatomic structures [10, 12, 13, 14]. They described problems in analyzing the internal details of (especially) solid lesions and organs.

The deficiencies of harmonic filtering have been largely overcome by the development of the alternative approach of phase inversion [17]. In our opinion, the theoretical advantage of PTHI over THI can be indirectly drawn from our results, although we did not directly compare PTHI to THI. Not only fluid-filled processes were better visualized and differentiated from pancreatic parenchyma: in comparison with BM, lesion conspicuity for solid processes was also enhanced (Table 4), lesion borders were more defined, and the internal structures were imaged with a high gray-scale range (Figs. 2, 3).

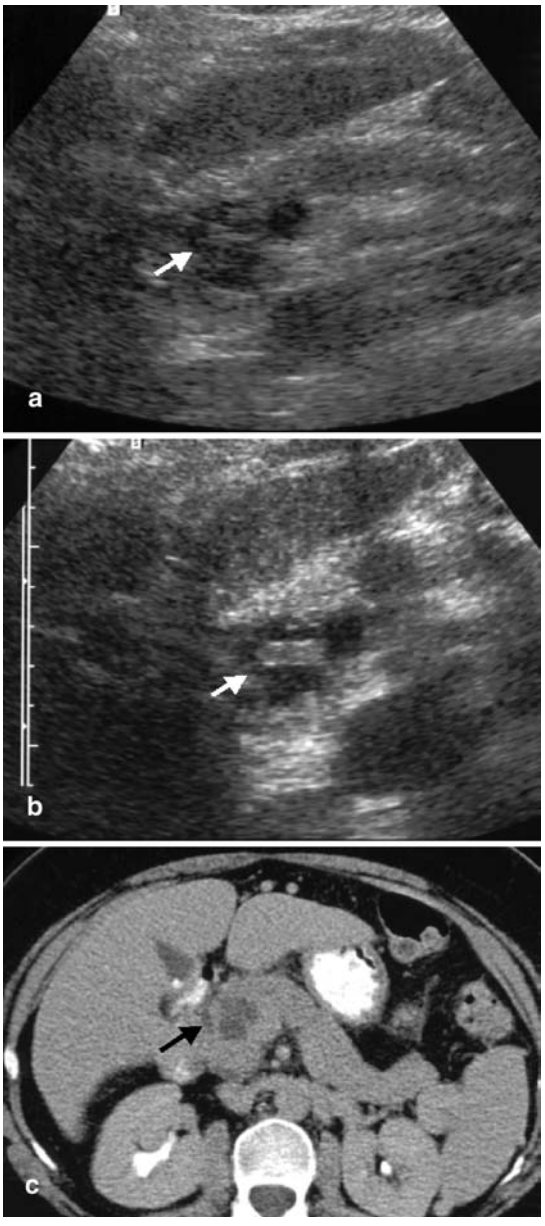

Fig. 1a–c A 62-year-old woman with a mixed cystic–solid tumor of the pancreatic head and histopathologically carcinoid tumor with a diameter of 20 mm. **a** B-mode US (BM) shows a poorly delineated lesion with mixed echogenicity (*arrow*). **b** With phase-inversion tissue harmonic imaging (PTHI) the lesion borders are more defined as cystic, and solid (*arrow*) portions of the tumor are clearly delineated. **c** Computed tomography scan of same region (*arrow*)

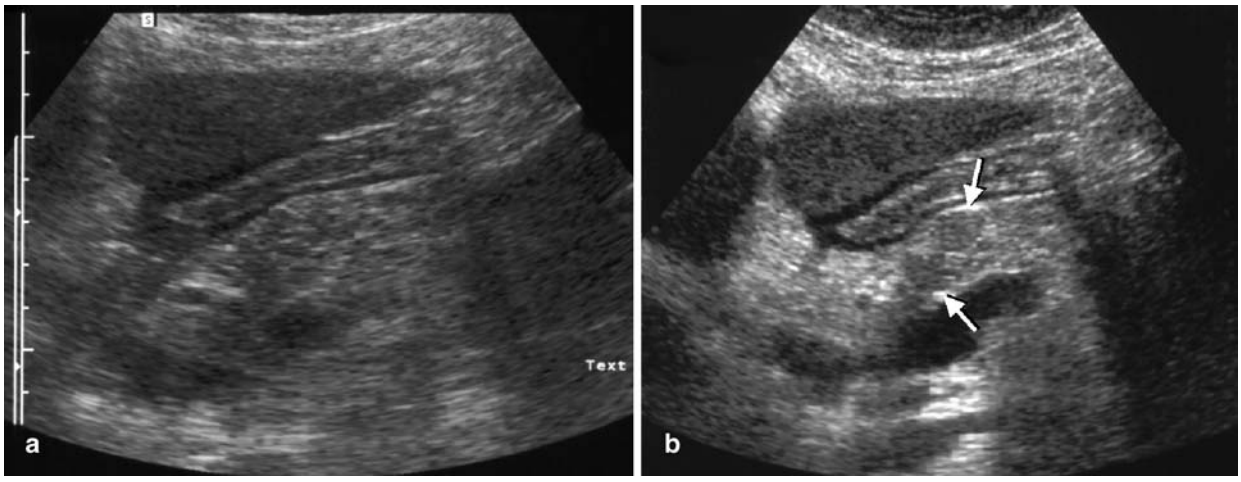

Fig. 2a, b Small (15-mm) adenocarcinoma of the pancreatic head in a 57-year-old man. **a** With BM, the pancreatic head shows irregular parenchymal echogenicity and the pancreatic head is not enlarged. The carcinoma was not noticed using this modality. **b** Phase-inversion tissue harmonic imaging offers excellent tissue contrast, so that two subtle lesions of slightly lower echogenicity (*arrows*), within normal parenchyma, could be delineated

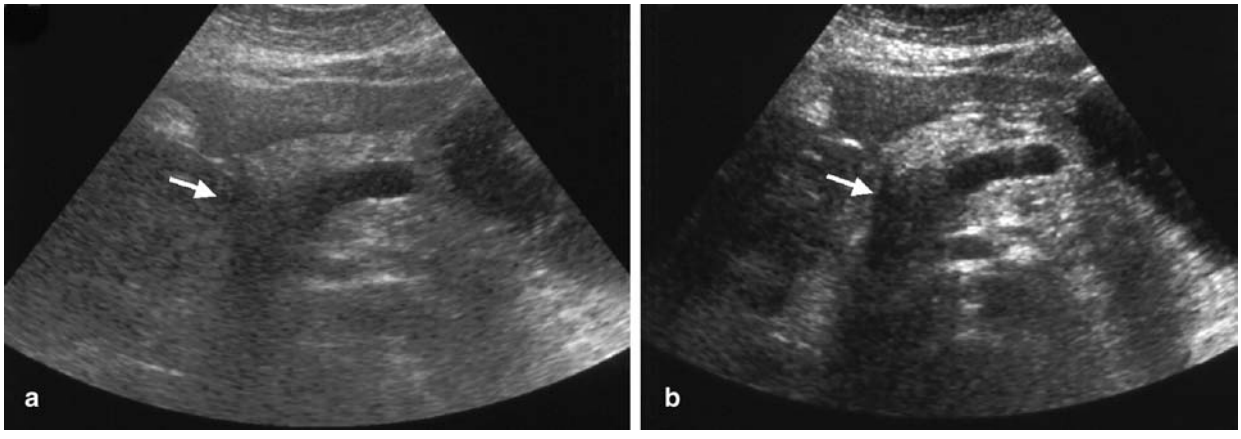

Fig. 3a, b Carcinoma of the pancreatic head (30 mm) in a 53-year-old woman. **a** With BM, the lesion could be visualized retrospectively after being detected with PTHI (*arrow*). It was not detected in the regular scan. The BM shows extensive reverberations obscuring the lesion and the dependent part of the image. **b** Only with PTHI could the lesion be regularly detected (*arrow*). The tumor of intermediate echogenicity is demonstrated unequivocally, and even an anechoic rim is seen

For THI with high-pass filtering in comparison with BM, especially differentiating internal structures of solid lesions has been previously reported as a problem [10, 12, 13, 14]. In our study the two radiologists, who evaluated image quality on hardcopy films performed with PTHI, did not report this.

Our subjective impression that PTHI has the ability to produce images with a wide dynamic range has been confirmed by the findings of Jang et al. [14]. They showed that PTHI is superior to THI and BM with better conspicuity and resolution for internal characteristics of cystic and solid hepatic lesions.

The two main disadvantages arising from phase-inversion technique are based on the need for two US pulses to be transmitted. Not only is the frame rate halved, but also the possibility of motion artifacts [29] is given. Both sonographers did not feel limited by the reduced frame rate, and no motion artifacts were observed.

The delineation of the pancreatic tail as a more distant structure was also evaluated. We found a statistically significant improvement in the visualization of the pancreatic tail with PTHI especially in the depth (Table 4).

With regard to the subjective, operator-dependent nature of sonographic examinations, our study was limited. For reasons of standardization, we did not allow a change of imaging and post-processing parameters with exception of the image gain and depth of the focal zone. We had to make compromises in defining fixed parameters such as the gray-scale used and the compression of

dynamic range; thus, parameters might have been in favor of one imaging modality. One impression of PTHI was that of greater differences in brightness, and hence, a rough contrast. For a routine clinical setting it might be useful to adjust the post-processing parameters so that PTHI images look similar to examinations with BM; however, we cannot predict if this covers the advantages of PTHI that we found in the present study in which no adjustment, except for gain and focal zone, was allowed.

Conclusion

Phase-inversion tissue harmonic imaging is a relatively new US technology which uses whole-numbered harmonics of the fundamental frequencies which are transmitted by the US probe. In the present study PTHI proved to provide an enhanced overall image quality, better lesion conspicuity, and advantages in fluid–solid differentiation in comparison with BM. These results were statistically significant. In the detection of pancreatic lesions, especially in smaller lesions up to 1 cm in diameter, PTHI had a higher sensitivity without a loss of specificity, although the differences were not statistically significant. Previously reported disadvantages of harmonic imaging with filtering techniques seem to be overcome by phase-inversion technique. Phase-inversion tissue harmonic imaging offers a wide dynamic range and good evaluation of the internal morphology of solid lesions, even for structures located more distantly. Although general disadvantages, especially non-diagnostic scans due to bowel gas and obesity, sometimes limit the diagnostic performance of pancreatic US compared with other cross-sectional modalities, i.e., contrast-enhanced CT or MRI, PTHI seems to be superior to BM in the evaluation of pancreatic abnormalities. Further studies, concentrating on smaller lesions, may be able to confirm our results with statistical significance.

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