Comparison of conventional B-scan, tissue harmonic imaging, compound imaging and tissue harmonic compound imaging in neck lesion characterisation

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Abstract In recent years, further technical developments of ultrasound scanning techniques, such as tissue harmonic imaging (THI) and compound imaging (CI), have become available and promise considerable improvement in image quality. No comparative assessments have yet been made of their systematic use in the head and neck. We studied 313 lesions of the head and neck detected on ultrasound scanning. Ultrasound images were obtained using a state-of-the-art scanning system. Two experts evaluated the images obtained for each lesion with conventional B-scan mode (BSCAN), THI, CI, and tissue harmonic compound imaging (THICI) with respect to four different aspects of image quality. Largely concordant results were found for each of the parameters studied: overall image quality, tissue contrast, lesion conspicuity, and internal structure. Evaluations of CI and THICI were frequently ranked higher ($p < 0.001$) than BSCAN and THI ($p < 0.001$). Images obtained in BSCAN mode often had better scores than images in THI mode alone ($p < 0.001$). Comparison of CI and THICI showed no statistically significant differences for any of the parameters studied. After a learning period, compound imaging methods improve image quality of the soft tissues of neck and may be included in the routine settings of ultrasound systems.

Keywords Ultrasound scanning · Harmonic study · Tissue harmonic imaging · Spatial compound imaging · Head and neck

Introduction

As high-resolution B-scan ultrasound offers many advantages over other methods, it is one of the methods most frequently used for diagnostic imaging of inflammatory and neoplastic changes in the soft tissues of the head and neck [1]. Scanning serves two basic functions: to identify a lesion and to characterise it. Diagnostic impact is mainly influenced by operator experience and the application of Doppler or duplex sonography. In the previous years, further technical developments of ultrasound scanning techniques, such as tissue harmonic imaging (THI) and compound imaging (CI) have become available and achieved considerable improvement in image quality [2–4].

As hardware upgrade, these functions are currently available in modern ultrasound systems offered by most manufacturers. For image processing, THI uses high-frequency non-linear sound wave components, generated by frequency filtering, phase inversion and cancellation, or coded harmonic frequencies. As a result, greyscale layer images that omit the fundamental frequencies are created. The better contrast thus obtained and the reduced susceptibility to artefacts have led to a standardised use of this method in various disciplines [5–11].

Compound imaging is based on the principle of interpolating multiple coplanar layer images from various intromission angles into a combined image. This improves

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tissue contrast, image quality, and the assessment of internal structure. Although these techniques have so far been tested for their usefulness, there are, as far as we know, no studies comparing the use of these new ultrasound techniques in the head and neck area.

Our study had three objectives: firstly, to investigate inter-observer agreement in the evaluation of ultrasound image sets read by two independent experts. Moreover, the present study aimed to demonstrate differences between conventional B-mode ultrasound scanning (BSCAN), THI, CI, and a combination of these two new methods (THICI) on the basis of several assessment criteria. The third aim was to find out whether it would be worthwhile introducing THI and CI into routine ultrasound scanning of the head and neck as reported for other areas.

Subjects and methods

During the study period from August to November, we investigated 313 tissue lesions detected on ultrasound scans of 169 patients (66 women, 103 men) aged 7–90 years. These lesions comprised lymph nodes, cysts, and solid space-occupying lesions of the thyroid and major salivary glands. All images were obtained using a state-of-the-art ultrasound system (Acuson Antares, Siemens Medical Solutions USA, Inc.) with a VF10-5 linear scanner (5–10 MHz, Siemens Medical Solutions USA, Inc.). This system offers the possibility of combining compound imaging with tissue harmonic imaging. The technology of THI and CI integrated in the Siemens system is now made available by other ultrasound system manufacturers. Each lesion was investigated in the following order: BSCAN, THI, CI, and THICI. The level of insonation neither changed for any of the techniques, so that the images obtained would be as similar as possible nor were the basic system settings altered, except for the examiner optimising the gain for each image. Images were stored digitally both in the scanner and using electronic medical record software (Clinic WinData 6.07.17; E&L Medical Computer Systems, Germany). All patients gave informed consent to the investigation and anonymous use of their medical data.

Images obtained in one set of findings were randomly mixed and placed adjacent to each other on the computer screen for evaluation. All indications of the technique used were removed beforehand. The images were then independently assessed by two ultrasound experts with level 3 certification from the "*Deutsche Gesellschaft für Ultraschall in der Medizin*" [German Society of Ultrasound in Medicine]. The evaluation criteria were: overall image quality, tissue contrast, lesion conspicuity, and internal structure of the lesion.

Overall image quality was defined as the general assessment of spatial resolution, accuracy of detail, and background noise. Technical artefacts, such as repetition echoes, speckles, and clutter were also taken into account. Tissue contrast was the criterion for evaluating the image quality of tissues of different impedance (muscle, fascia, blood vessels, and bone). Lesion conspicuity looked at the contrast between a lesion and the surrounding tissue and distinctness with which it could be seen. The fourth parameter, internal structure, assessed the quality of the echogenicity within the lesion. The examiner rated overall image quality, tissue contrast, lesion conspicuity, and internal structure on a scale from one (poorest quality) to four (optimal demonstration of tissues).

Cohen's kappa with a 95% confidence interval (CI) was used to quantify inter-observer agreement between the two examiners. Concordance is considered to be strong with $\kappa > 0.75$, moderate when values are between 0.40 and 0.75, and weak with $\kappa < 0.40$. As a non-parametric test, Friedman's test was used for the qualitative assessment of different ultrasound techniques (assessment of one of the examiners) with paired post hoc comparisons using the Wilcoxon signed-rank test. The null hypothesis that all modes are the same was rejected if $p < 0.05$. The same applied to the subsequent paired comparisons. Statistical analysis was carried out using the SYSTAT 12 program (SYSTAT Software Inc., San Jose).

Results

The inter-observer agreement in the assessment of the quality of the findings in the four imaging modes is shown in Table 1.

Inter-observer agreement was lowest for the evaluation criteria of overall image quality and internal structure in the BSCAN modality. Overall, moderate concordance was found between the independent experts, with maximum values for tissue contrast and lesion conspicuity of 0.558 (95% CI 0.473; 0.642) and 0.618 (95% CI 0.530; 0.707), respectively. Greater concordance, more than 0.4, was seen between CI and THICI. Weak concordance was found for tissue contrast using THI and CI alone (0.288 and 0.218, respectively). In general there was no strong inter-observer agreement.

The assessment of quality of the findings in each category (overall image quality, tissue contrast, lesion conspicuity, internal structure) is depicted in Table 2.

There were similar results for each of the four parameters studied—overall image quality, tissue contrast, lesion conspicuity, and internal structure.

Table 1 Inter-observer agreement of the image assessment criteria, quantified by Cohen's kappa (95% CI) ($n = 313$)

	BSCAN	THI	CI	THICI
Overall image quality	0.312 (0.206–0.419)	0.330 (0.239–0.422)	0.490 (0.410–0.570)	0.414 (0.328–0.500)
Tissue contrast	0.350 (0.240–0.460)	0.288 (0.212–0.364)	0.218 (0.158–0.279)	0.558 (0.473–0.642)
Lesion conspicuity	0.349 (0.265–0.433)	0.284 (0.195–0.372)	0.274 (0.201–0.324)	0.618 (0.530–0.707)
Internal structure	0.285 (0.188–0.382)	0.373 (0.274–0.472)	0.548 (0.461–0.634)	0.503 (0.417–0.589)

BSCAN B-scan mode, *THI* tissue harmonic imaging mode, *CI* compound imaging mode, *THICI* tissue harmonic imaging mode combined with compound imaging mode

Table 2 Comparative evaluation of the four modes ($n = 313$)

	1	2	3	4
BSCAN				
Overall image quality (%)	15.02	66.77	17.89	0.32
Tissue contrast (%)	14.38	73.16	12.14	0.32
Lesion conspicuity (%)	16.29	41.53	39.30	2.88
Internal structure (%)	28.75	59.42	11.50	0.32
THI				
Overall image quality (%)	46.01	48.88	4.79	0.32
Tissue contrast (%)	56.23	42.49	0.96	0.32
Lesion conspicuity (%)	20.13	48.24	30.03	1.60
Internal structure (%)	42.17	52.72	4.47	0.64
CI				
Overall image quality (%)	0.00	0.32	12.78	86.90
Tissue contrast (%)	0.00	0.32	14.06	85.62
Lesion conspicuity (%)	0.32	4.15	19.17	76.36
Internal structure (%)	0.32	3.83	24.60	71.25
THICI				
Overall image quality (%)	0.00	0.96	10.22	88.82
Tissue contrast (%)	0.32	0.96	13.74	84.98
Lesion conspicuity (%)	0.32	1.92	18.53	79.23
Internal structure (%)	0.32	2.56	26.20	70.93

BSCAN B-scan mode, *THI* tissue harmonic imaging mode, *CI* compound imaging mode, *THICI* tissue harmonic imaging mode combined with compound imaging mode. 1 (poorest quality)–4 (optimal quality)

CI and THICI showed higher assessment ratings considerably more often than BSCAN and THI ($p < 0.001$). The images in BSCAN mode were rated better than the images in THI mode alone ($p < 0.001$).

Irrespective of the parameter, no statistically significant difference was found in the comparison of CI and THICI. All the four parameters studied had p values greater than 0.05 ($p = 0.635$–0.840). With respect to tissue contrast, CI more frequently had a higher rating than THICI.

The Wilcoxon signed-rank test demonstrated the superiority of BSCAN over THI and the even better image quality of modes using CI (Table 3).

Table 3 Statistical comparison of the four methods with the Wilcoxon signed-rank test

Overall image quality	THI < BSCAN ≪ CI = THICI
Tissue contrast	THI < BSCAN ≪ CI = THICI
Lesion conspicuity	THI < BSCAN ≪ CI = THICI
Internal structure	THI < BSCAN ≪ CI = THICI

BSCAN B-scan mode, *THI* tissue harmonic imaging mode, *CI* compound imaging mode, *THICI* tissue harmonic imaging mode combined with compound imaging mode

Discussion

The study presented here compares the qualitative assessment of BSCAN with that of THI, CI and the combination of two, in the near field of soft tissues of the neck. We aimed to verify the theoretical improvement of image quality through the assessments by two independent ultrasound experts. The concordance of the results in this study showed satisfactory to good inter-observer agreement, similar to that found by other working groups [5]. The compound images obtained from the multiple individual views are clearly different from the images generated by BSCAN and THI alone (Fig. 1). The new modes, CI and THICI, showed better concordance in the inter-observer comparison than either BSCAN or THI. Particularly striking, however, were the different assessments of tissue contrast with THI and CI, as only weak agreement was seen for this parameter. After viewing the data, the first expert gave CI the highest rating in 85% of cases, while the second did this in only 40%. This difference can be explained by the subjective definition of "contrast" related to tissues of different acoustic impedance. The two experts agreed that the less grainy appearance of the images in compound mode is an advantage in demonstrating tissue elements in greater detail (Fig. 2). A further and related aspect was the individual learning curve of the observer confronted with THI and CI. Viewing THI and CI images gives a different depiction of ultrasonographic tissue structure. These partially differ significantly from the "expected" way a lymph node is conventionally visualised.

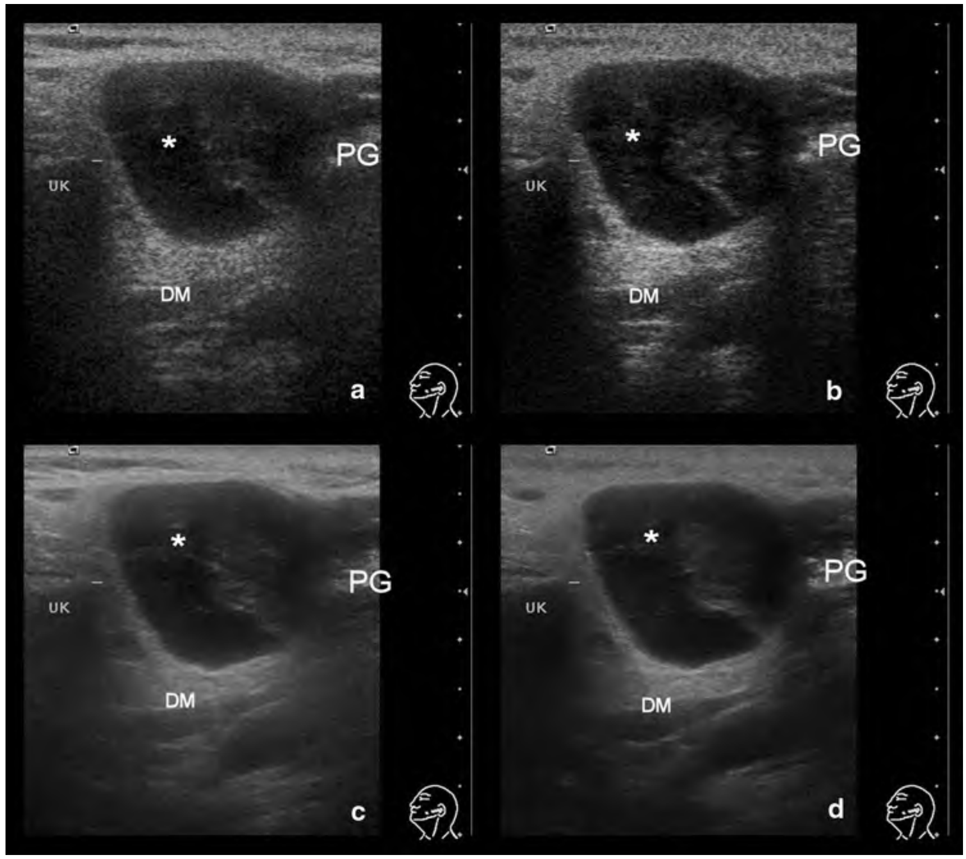

Fig. 1 A 74-year-old woman with Warthin tumour of the left parotid gland (PG). *UK* lower jaw, *DM* digastric muscle and *asterisk* adenoma. **a** Transverse BSCAN image through the inferior pole of the gland showing a rounded hypoechoic space-occupying lesion. **b** Corresponding THI image with better contrast of the internal echoes and clearer demonstration of the distal ultrasound phenomenon, but coarser graining of the tissue. **c** Compound image with improved lesion conspicuity and internal structure of the lesion. In comparison, the combination of THI and CI (THICI) brings little further improvement of image quality (**d**)

The results of our study showed that the use of CI and THICI offer a considerable improvement in the overall image quality, tissue contrast, lesion conspicuity and internal structure of lesions seen on ultrasound scanning. This confirms the advantages of CI and THICI to be expected theoretically, and the findings of studies from other disciplines. The clear demonstration of distal echo reinforcement in cystic lesions with THI was particularly valued. This assessment is shared by Seo et al. [8] in the diagnostic investigation of breast lesions. The poorer performance of THI alone in the ratings for all parameters is particularly striking. The information provided by THI, generated by non-linear "harmonic" tissue reflections often shows an attenuated hypoechoic picture. This means that deeper regions are only poorly imaged in some patients, despite near-field (maximum depth 45 mm) application of THI. Possible reasons for the poorer subjective assessment of the image quality with THI are mentioned by Mesurolle et al. and Cha et al. [12, 13]. In near-field investigations, space-occupying lesions were more clearly visible on THI when there was a background of fatty tissues; in the absence of such a background, the method was no better. The smaller frequency component of THI leads to a loss of axial resolution, especially in the high-frequency ranges used in the neck. Furthermore, THI gives a grainier image than CI and is more susceptible to motion artefacts than B-scan mode. In majority of the findings, compounding achieved a better image quality. In relation to real-time scanning, it has to be mentioned that slow transducer movement is also necessary with compound imaging. We can confirm the potential of this method to reduce artefacts (e.g. speckles and clutter) and allow the better demonstration of internal structure and tissue contrast. Speckle reduction is reflected in the improved demarcation of the lesions and better visualisation of areas of poorer contrast or echodense structures such as microcalcification. Clutter from the technical generation of the image from various angles and averaging of the individual images obtained is likewise reduced. Detailed demarcation is a particular advantage in the neck, where many different anatomical structures are confined within a narrow space, and justifies the use of CI. Given the lack of superiority of THI over BSCAN, it is not surprising that combining CI with THI brought no greater advantage than that seen with compound imaging.

Our study had certain limitations: we used only one ultrasound system by the Siemens company—the settings and results cannot necessarily be extrapolated to other ultrasound systems. This applies particularly to the striking results we found for the use of THI alone; different

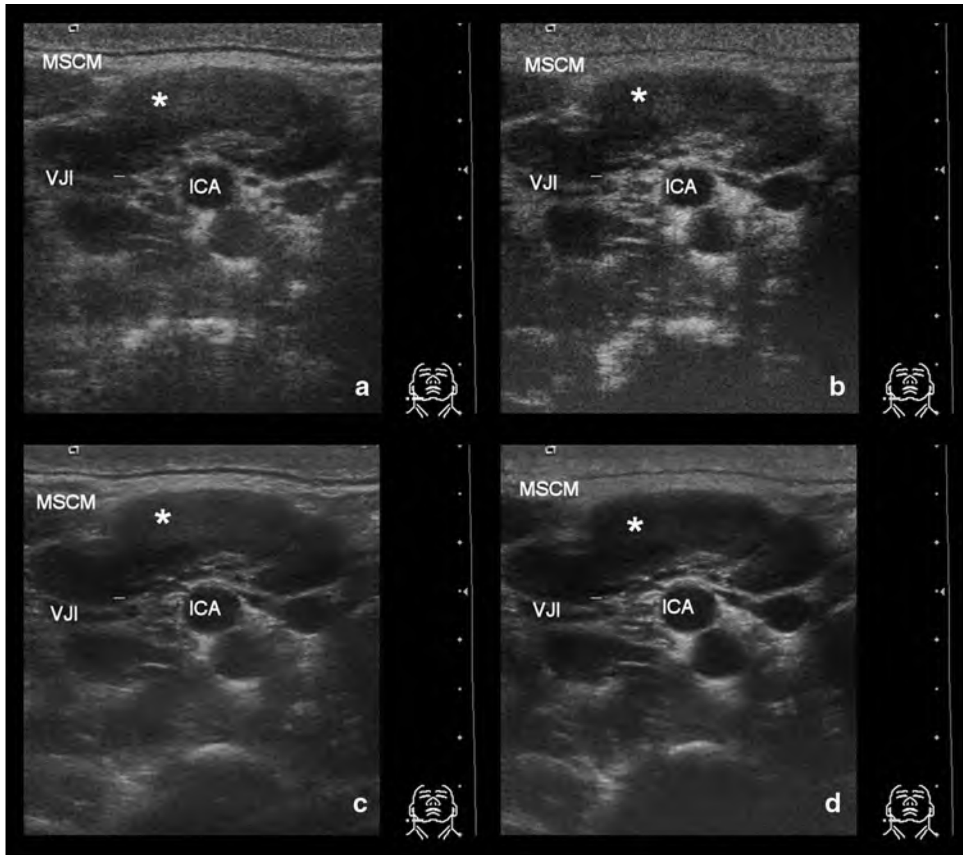

Fig. 2 A 27-year-old man with an acute right-sided lymphadenitis of the neck at Level II shown on ultrasound scan (transverse section). *MSCM* sternocleidomastoid muscle, *VJI* internal jugular vein, *ICA* internal carotid artery and *asterisk* lymph node. **a** Transverse BSCAN image through the soft tissues of the neck showing a polycyclic configured lymph node with markings in the hilum, situated medially below the sternocleidomastoid muscle. **b** Corresponding THI image with the node slightly more distinct from its surroundings but with coarser graining of the tissue. **c** Compound image with better lesion conspicuity, tissue contrast and internal structure of the lesion. **d** THICI allows the lymph node hilum and nodular internal structure of the lesion to be seen even more clearly

resolutions have been described depending on how the harmonics are generated [10, 14]. In addition, retrospective evaluation of individual static images does not correspond to the situation found in real-time scans, as the examiners do not have the possibility of judging the individual settings under the prevailing conditions or optimising them for their own viewing habits. The individual experience of the operator still has an influence of the general image interpretation that is hard to measure. There was only weak agreement between the two experts in the classification of the parameter tissue contrast in THI and CI; this may be due to discrepancies in the definition of contrast, the coarser grained THI heightened the differences in impedance more than CI and made boundaries more pronounced. As mentioned above, THI and CI require an initial accommodation period to get used to the different appearance of grey scale images.

Summarising our results, it can be seen that using tissue harmonic imaging alone in the neck region does not seem to have any advantages. As stated by Forsberg [4], all promising advances in grey scale imaging should be critically evaluated considering their clinical value in the field of application. However, CI or the combination of THI with CI appreciably improves the image quality. On the basis of the results presented here compound imaging may be implemented in the standard diagnostic investigation protocol for the head and neck, especially in an investigation performed by younger operators. The key role in ultrasound investigation nowadays still remains the grey scale and duplex sonography in the hand of an experienced operator.

Conflict of interest statement None.

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