Research paper

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Ultrasound in intensive care unit patients: applications, observations, and comparison of two established ultrasound methods

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Abstract

Aim: To evaluate the benefit of abdominal ultrasonography performed routinely and thus independently of symptomatology in patients in the intensive care unit, and to assess the value of a portable ultrasound device. Diagnostic yield and documented results with clinical consequences were considered and compared with findings obtained using a high-end ultrasound device. **Material and methods:** A total of 120 patients of an internal medicine intensive care unit were included over 12 months. The investigator had limited experience in sonography (approximately 300 abdominal sonographies performed). The abdomen and basal portions of the thorax were examined. **Results:** The most common pathological findings were renal cysts in 34/120 (28.3%), left-sided or right-sided pleural effusions in 33/120 (27.5%) and 29/120 (24.2%) patients, respectively, dilatation of the vena cava in 24/120 (20.0%), and urinary retention in 14/120 (11.7%) patients. In 13/120 (10.8%) patients, the sonographic examination resulted in a diagnostic consequence, while in 38/120 (31.7%) patients in a therapeutic consequence. Among the false-negative findings using the hand-held ultrasound device, no finding was of therapeutic relevance. Four findings that were missed by the hand-held ultrasound device were diagnostically significant: two lesions of the kidney, one lesion of the liver, and one case of urinary stasis kidney. **Conclusions:** With the hand-held ultrasound device, only 33 of 52 focal lesions were detected. Thus, a high-end ultrasound device cannot be replaced by a hand-held ultrasound device for this purpose, but certain clinical questions can be answered reliably with a hand-held ultrasound device (such as the presence of a puncture-worthy pleural effusion in patients with dyspnea, or verification of the volume status based on the diameter of the vena cava).

Introduction

Sonography is the primary imaging modality for a wide variety of medical conditions and is routinely used, primarily in internal medicine, but also in other specialties (e.g., surgery, gynecology, and urology)[1–5].

In patients in the intensive care unit (ICU), sonography is typically performed in response to specific symptoms and with a targeted question. Common indications include the search for the cause of circulatory arrest, hemodynamic instability, and dyspnea[6–10]. In addition, the placement of central venous catheters and the puncture of pleural effusions or ascites are routinely performed under ultrasound guidance as a standard procedure, which reduces the risk of complications[11,12].

A study in geriatric patients demonstrated that conventional abdominal ultrasonography, when performed as a standard procedure, provides diagnostically and therapeutically relevant additional information[13]. Whether standard, symptom-independent abdominal ultrasonography is of additional value requires further investigation[14,15].

Due to the advancement of ultrasound technology, including the development of small portable devices, bedside ultrasound examination is nowadays easily available and complements the physical examination. During the classic physical examination, including auscultation, cardiopulmonary pathologies – such as pericardial effusion, pleural effusion, or reduced systolic pumping capacity of the heart – can often be overlooked. Point-of-care sonography can be used to diagnose such pathologies[16,17]. The European Ultrasound Society (EFSUMB) recommends the use of portable or hand-held ultrasound devices (HHUSD)[18] in specific clinical situations for targeted questions that can be answered "yes" or "no"[19–20]. These include the assessment of free intra-abdominal fluid, pleural or pericardial effusion, aortic aneurysm, urinary retention, hydronephrosis, dilated bile ducts, space-occupying lesions correlating with palpable resistance, spleen size, and large gallbladder stones. In addition, imaging of fluid collections prior to punctures with HHUSD is recommended, as is positional control of urinary bladder catheters when appropriate[21].

Understanding the performance of portable ultrasound devices would be of interest, since in comparison to high-end US devices they are cheaper and better suited for use in space-limited environments.

The aim of this study was to investigate the usefulness of routinely performed conventional abdominal ultrasonography in ICU patients and to examine whether it provides diagnostically or therapeutically relevant additional information. The consequences of such findings included further imaging or endoscopic examination, respectively, a change in medication or interventional therapeutic measures. Furthermore, the study sought to assess whether there are significant differences between a conventional ultrasound scanner and a portable ultrasound scanner in the detection of pathological findings.

Patients and methods

Patient recruitment

The study had a unicentric observational design. Patients treated in the internal intensive care unit of the Caritas Hospital Bad Mergentheim in Germany (a primary care hospital) in 2019 were included in the study. Exclusion criteria were patient refusal or lack of capacity to provide informed consent.

Ultrasound equipment used

The Aixplorer device from SuperSonic Imagine was used as the high-end ultrasound device (HEUS). It was equipped with a convex transducer (XC6-1, 1–6 MHz) and a linear transducer (SL 10-2, 2–10 MHz). The Youkey Q7 was used as the HHUSD. It weighs 160 g and was used with a convex transducer attachment (C5-2Fs, 2–5 MHz). The device features B-mode as well as color Doppler and power Doppler capabilities. It was connected via an app to a smartphone (HTC U 11), which served as the display. Different examination modes could be selected via the app (e.g., abdomen, heart, vessels, kidneys). During the examination, certain parameters, such as total gain, penetration depth, focus and frequency, could be adjusted.

Examination procedure

Patients consented to the examination by means of an informed consent form, after which a systematic ultrasound examination of the abdomen and basal portions of the thorax was performed.

All examinations – both with the high-resolution and portable ultrasound scanners – were performed by the same examiner, a resident in internal medicine at Caritas Hospital in Bad Mergentheim with limited experience in sonography (approximately 300 abdominal sonographies performed). Patients were examined at the bedside in the internal medicine intensive care unit.

First, the patients were examined with the portable ultrasound device, directly followed by the high-resolution ultrasound scanner. The pathological findings obtained were divided into diagnostically and/or therapeutically relevant. Findings were considered diagnostically relevant if they could not be unequivocally classified as benign or were assessed as a potential risk for a complicated clinical course (e.g., renal failure due to urinary retention). The consequences of such findings included further imaging diagnosis or medical or interventional therapeutic measures. Further diagnostic workup was performed at a later time after stabilization of the patient's primary intensive care condition.

The following structures were studied:

- Liver: focal lesions, diameter of the right hepatic vein (measurement 1 cm below the junction with the vena cava), diameter of the portal vein (measurement extrahepatically in the area of the hepatic orifice), diameter of the ductus hepatocholedochus (in the area of the hepatic orifice), intrahepatic bile ducts, diffuse liver changes (increased echogenicity of liver tissue, liver cirrhosis);
- Gallbladder: longitudinal diameter, stones, sludge, polyps, wall thickening;
- Pancreas: size of the caput (left-right diameter) and corpus (anteroposterior diameter), focal lesions, diameter of the vena lienalis (anteroposterior diameter in the corpus region);
- Spleen: longitudinal diameter, focal lesions;
- Kidneys: longitudinal diameter, focal lesions, stones, urinary retention, adrenal space involvement;
- Aorta and vena cava: diameter of the aorta (anteroposterior infrarenal diameter), diameter of the vena cava (anteroposterior diameter measured 1–2 cm before confluence with the right atrium);
- Intestine: focal lesions, dilated intestinal loops, wall thickening[22,23];
- Urinary bladder: focal lesions, urinary retention;
- Reproductive organs: prostatic hyperplasia, focal prostatic lesions, focal uterine lesions;
- Peritoneal cavity: ascites;
- Heart (subcostal view): pericardial effusion, right heart enlargement;
- Pleura: pleural effusions, existing pleural sliding.

Statistical methods

Mean, standard deviation, minimum, and maximum were determined to describe the data. The pathological findings obtained with the HEUS device were set as the gold standard. By recording the false-negative findings, the sensitivity of the HHUSD could be calculated. To test

whether significant differences existed between the HEUS and HHUSD in detecting pathological findings, two comparative tests were performed. First, Cohen's kappa was calculated, serving in this context as a measure of intrarater reliability, where the same examiner uses the same measurement method at two different time points. On the other hand, differences between the ultrasound devices regarding pathological findings were evaluated by means of the McNemar test, typically applied in before-after comparisons to check the effectiveness of a therapeutic intervention. The t-test was used to determine whether the duration of examination with the HEUS and HHUSD was significantly different.

Ethics vote

The study was reviewed and approved by the Ethics Committee of the Baden-Württemberg Medical Association.

Results

Study population and study indication

A total of 120 patients were examined with both ultrasound devices. The mean age was 71.6 years. Of these, 79/120 (65.8%) were male and 41/120 (34.2%) were female.

In 109/120 (90.8%) patients, the ultrasound examination was performed independently of symptoms and without a specific question, as an extended physical examination. In the remaining patients, the ultrasound examination was performed with a specific question. The indications were as follows:

- Abdominal pain in 4/120 (3.3%) patients;
- Elevated liver enzymes in 3/120 (2.5%) patients;
- Tumor search in 2/120 (1.7%) patients;
- Infection focus search in 2/120 (1.7%) patients.

Image quality

For both examinations with the high-resolution ultrasound scanner and the portable ultrasound scanner, image quality was classified by the examiner as good, sufficient/adequate, or insufficient/inadequate. In 72/120 (60.0%) examinations performed with the HEUS, image quality was found to be good, in 36/120 (30.0%) sufficient, and in 12/120 (10.0%) insufficient. For examinations with the HHUSD, image quality was rated as good in 68/120 (56.7%), adequate in 33/120 (27.5%), and inadequate in 19/120 (15.8%). The following patient-related factors impaired image quality: obesity, limited mobility, elevated upper body posture due to respiratory distress, and patients on bed rest following cardiac catheterization.

Pathological findings in the abdomen (yes/no parameters)

The data are presented in Tab. 1.

Tab. 1. Abdominal and thoracic pathologic findings arranged by detection sensitivity

Pathology	Prevalence	False negative	Sensitivity	False positive	Specificity
Focal lesion, gallbladder	2,5% (3/120)	3	0.00%	0	100%
Focal lesion, kidney	2,5% (3/120)	2	33.30%	1	99,20%
Focal lesion, liver	4,2% (5/120)	3	40.00%	0	100%
Focal lesion, spleen	4,2% (5/120)	3	40.00%	1	99,10%
Urinary stasis in kidney	1,7% (2/120)	1	50.00%	0	100%
Extension of the DHC	3,3% (4/120)	2	50.00%	1	99,20%
Enlarged right ventricle	7,5% (9/120)	4	55.60%	4	96,50%
Ascites	9,2% (11/120)	3	72.70%	0	100%
Increased echogenicity, liver	16,7% (20/120)	5	75.00%	0	100%
Gallbladder stone	6,7% (8/120)	2	75.00%	2	98,20%
Kidney cysts	28,3% (34/120)	8	76.50%	0	100%
Splenomegaly	10,0% (12/120)	2	83.30%	0	100%
Pericardial effusion	5,8% (7/120)	1	85.70%	3	97,40%
Pleural effusion, right-sided	24,2% (29/120)	4	86.20%	0	100%
Pleural effusion, left-sided	27,5% (33/120)	3	90.90%	2	97,80%
Dilatation of the vena cava	20,0% (24/120)	0	100.00%	6	94,10%
Aortic aneurysm	0,8% (1/120)	0	100.00%	0	100%
Focal lesion, pancreas	1,7% (2/120)	0	100.00%	0	100%
Urinary bladder obstruction	11,7% (14/120)	0	100.00%	0	100%
Enlarged prostate	3,3% (4/120)	0	100.00%	0	100%
Ileus sign	1,7% (2/120)	0	100.00%	0	100%

Diagnostically relevant findings

Ultrasonography revealed diagnostic consequences in 13/120 (10.8%) patients:

- In 3/120 (2.5%) patients with a focal lesion of the kidney underwent contrast-enhanced ultrasound (CEUS), which revealed no evidence of malignancy.
- In 1/120 (0.8%) patients with an hyperechoic lesion of the liver, a check was performed by an experienced investigator, which revealed the presence of a hemangioma.
- In 1/120 (0.8%) patients with multiple hepatic foci, endoscopic workup revealed metastases from colorectal carcinoma.
- In 1/120 (0.8%) patients with an inhomogeneous liver lesion, biopsy of the mass revealed malignancy.
- In 1/120 (0.8%) patients with a hyperechoic lesion of the spleen, sonography performed by an experienced investigator classified the lesion as benign with a recommendation for follow-up.
- In 1/120 (0.8%) patients with a pancreatic space-occupying mass and dilated DHC, further diagnosis by CT and endoscopic ultrasound revealed pancreatic cancer.
- 1/120 (0.8%) patients with a cyst in the pancreas underwent endoscopic ultrasound, which yielded findings of a lateral duct intraductal papillary mucinous neoplasm (IPMN).
- In 2/120 patients (1.7%) with prostate enlargement and 2/120 (1.7%) patients with urinary retention, referral to a urology specialist was made. Regarding the prostate enlargement, no evidence of malignancy was detected. The two patients with urinary retention underwent a CT scan, which showed no evidence of stone disease or urothelial carcinoma.

Therapeutically relevant findings

Therapeutic consequences were identified in 38/120 (31.7%) patients:

- Parenteral volume administration was reduced or discontinued in 5/120 (41.7%) patients with a dilated vena cava.
- In 16/120 (13.3%) patients with a dilated vena cava, therapy with diuretics was started or existing diuretic medication was intensified.
- 11/120 (9.2%) patients with urinary retention had a transurethral urinary catheter placed.
- 6/120 (5.0%) patients with large pleural effusions underwent pleural puncture due to anticipated respiratory impairment during increasing mobilization.

Diagnostic accuracy of the HHUSD

The diagnostic accuracy of portable ultrasound devices in relation to all pathological findings detected was one of the key aims of this study. 114/146 (78.1%) of the abdominal pathologies identified with the HEUS were also detected with the HHUSD. Among the false-negative findings, none were of therapeutic relevance, and four were diagnostically significant: two hypoechoic lesions of the kidney, one hyperechoic lesion of the liver, and one case of renal urinary stasis.

66/78 (84.6%) of thoracic pathologies detected with the HEUS were diagnosed with the HHUSD. Among the false-negative findings, none was of diagnostic or therapeutic relevance.

A total of 180 of the 224 pathological findings (80.4%) were diagnosed using the HHUSD.

Comparison between HEUS and HHUSD in terms of pathological findings

The total number of pathological findings in the abdomen and thorax is summarized in Tab 1.

The HHUSD showed varying performance for certain parameters. In Tab. 1, pathologies are sorted for sensitivity. However, this is limited for several reasons: firstly, the limited number of cases due to prevalence and patient number; secondly, the fact that some findings, such as ascites, are not binary (yes/no) but their detection depends on their extent.

Parameters considered as problematic included dilatation of the bile duct and enlargement of the right ventricle. When the following pathological findings were visualized, Cohen's kappa showed very good agreement between the HEUS and HHUSD: increased echogenicity of liver tissue ($\kappa = 0.83$), ascites ($\kappa = 0.83$), pericardial effusion ($\kappa = 0.92$), right-sided pleural effusion ($\kappa = 0.90$), and left-sided pleural effusion ($\kappa = 0.94$). There was good agreement for the detection of dilated vena cava and urinary retention ($\kappa = 0.77$ and $\kappa = 0.79$, respectively).

Examination time

The exact scan time was documented in a total of 46 patients. The average scan time was 16.49 ± 2.60 minutes (11.07–24.62) with the HEUS and 19.66 ± 3.97 minutes (9.77–34.0) with the HHUSD. Using t-tests, a statistically significant difference in mean scan time was demonstrated between the two groups ($p < 0.05$).

Discussion

The purpose of this study was to evaluate the utility of conventional abdominal ultrasonography in ICU patients and to determine whether there are significant differences between the HHUSD and HEUS in the detection of pathological findings.

Of the 120 patients investigated, 109 (90.8%) were systematically examined without any specific diagnostic questions. Based on the results of the study presented here, abdominal sonography performed as a standard procedure in ICU patients appears justified, as it yielded diagnostically relevant findings in 13/120 (10.8%) patients and therapeutically relevant findings in 38/120 (31.7%). In addition to findings that directly led to a change in intensive care management (e.g., dilatation of the vena cava), the standard sonographic examination also revealed prognostically relevant findings that may influence decisions regarding escalation or limitation of therapy in intensive care settings. For example, the detection of a metastasized tumor with an unfavorable prognosis may be decisive for determining a limitation of intensive care measures in accordance with the patient's wishes (e.g., refraining from resuscitation in case of cardiovascular arrest)[24,25]. Of course, the patient's comorbidities, general condition, and the severity of the intensive care disease are also important factors.

The number of therapeutically relevant findings obtained in this study is consistent with the data in the available literature. In the study by Schacherer *et al.*[12], a total of 400 patients in an internal medicine or surgical intensive care unit underwent abdominal ultrasonography. In 116/400 (29.0%) patients, sonography was performed as a screening procedure without any specific diagnostic question. In 79/400 (19.8%) patients, a therapeutically relevant finding was detected. Lichtenstein *et al.*[26] reported therapeutically relevant findings in 33/150 (22.0%) patients in the ICU by performing abdominal ultrasonography as a standard procedure.

Further diagnostic workup was undertaken in the following cases: 3/120 patients (2.5%) with focal renal lesions, 3/120 (2.5%) with focal liver lesions, 1/120 (0.8%) with an echoic splenic lesion, 1/120 (0.8%) with a solid pancreatic mass, 1/120 (0.8%) with a cystic pancreatic lesion, 2/120 (1.7%) with prostatic enlargement, and 2/120 (1.7%) with urinary retention. In three cases, further workup revealed a malignancy requiring treatment that might have been missed without the routine use of ultrasonography. Focal organ lesions are often detected as incidental findings on imaging (e.g., sonography or computed tomography). Kelly *et al.*[27] examined incidental findings noted on computed tomography in 1155 patients presenting to the emergency department with abdominal complaints. Among the 700 incidental findings, 24 were ultimately diagnosed as malignancies. Of the 24 patients with malignancy, six had localized tumor disease that was potentially curable.

Among the therapeutically relevant findings, dilatation of the vena cava was the most frequent (Fig. 1). This led to a change in volume management in 21 patients. In intensive care medicine, the diameter and respiratory-related caliber variation of the vena cava are specifically determined in hemodynamically unstable patients to assess volume status[28]. In addition, 11/120 (9.2%) patients with urinary retention received a transurethral bladder catheter and 6/120 (5.0%) patients with large pleural effusions underwent pleural puncture.

In the present study, the diagnostic accuracy of portable ultrasound devices with respect to all abdominal pathologies identified with the HEUS was 78.1%, which is within an acceptable range. In their work on geriatric patients, Fröhlich *et al.*[13] demonstrated a higher sensitivity of 89.5% using the HHUSD. Wastl *et al.* [29,30] investigated the utility of the HHUSD in the emergency medical setting in patients who required abdominal ultrasonography for various reasons in a blinded study. They were able to reliably visualize gallbladder stones (sensitivity 83.3%, specificity 89.5%), gallbladder sludge (sensitivity 100%, specificity 96.9%), signs of ileus (sensitivity 87.5%, specificity 60.0%), ascites (sensitivity 88.9%, specificity 93.1%), and pleural effusions (sensitivity 85.7%, specificity 100%) compared with the HEUS using a portable ultrasound device.

Among the false-negative findings, four were diagnostically significant: two lesions of the kidney, one lesion of the liver, and one case of urinary stasis kidney. Further workup resulted in the diagnosis of two renal parenchymal humps and a hemangioma; with regard to the urinary stasis kidney, an outpatient urological evaluation was recommended after CT showed no evidence of urolithiasis or urogenital tumor. No therapeutically relevant findings were missed with the HHUSD. In the present study, the HEUS and HHUSD showed very good agreement in demonstrating increased echogenicity of liver tissue ($\kappa = 0.83$) and ascites ($\kappa = 0.83$), and good agreement in identifying a dilated vena cava ($\kappa = 0.77$) and urinary retention ($\kappa = 0.79$). Other authors also demonstrated that certain clinical questions can be reliably answered with HHUSD[13,31–33]. In their study, Dalen *et al.* [33] reviewed the accuracy of a portable ultrasound device in determining the diameter of the vena cava compared with a high-resolution device. The examination with the portable device was performed by nurses who had received prior training, while the examination with the high-resolution device was conducted by cardiologists. This showed good agreement between the HHUSD and HEUS. In contrast, Wastl *et al.* [29] did not find a strong correlation between the diameters of the vena cava determined with the HEUS and HHUSD. Moreover, due to the low specificity of the HHUSD in assessing respiratory variability of the vena cava, the authors concluded that the HHUSD is not suitable for checking volume status. Kameda *et al.*[31] examined the kidneys of 100 patients for the presence of urinary retention using both HEUS and HHUSD. The examination with the portable device was sufficiently sensitive enough to reliably exclude urinary retention. In studies of trauma patients, the sensitivity of portable ultrasound devices in detecting free intraperitoneal fluid was investigated[34,35]. The authors found a sensitivity range of 77% to 88.9%. According to Kirkpatrick *et al.*[34], in 3.8% of patients an injury requiring intervention was missed that was not associated with free intraperitoneal fluid. They concluded that HHUSD examinations cannot replace computed tomography as the gold standard.

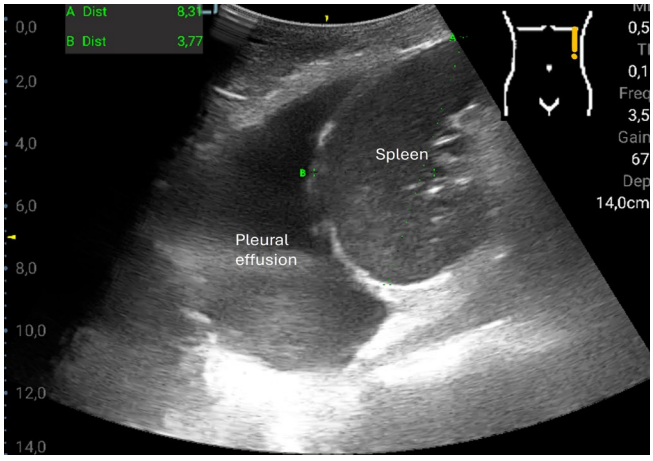

Fig. 1. *Sonographic image of a large left-sided pleural effusion captured with the Youkey Q7. The patient received therapeutic pleural drainage*

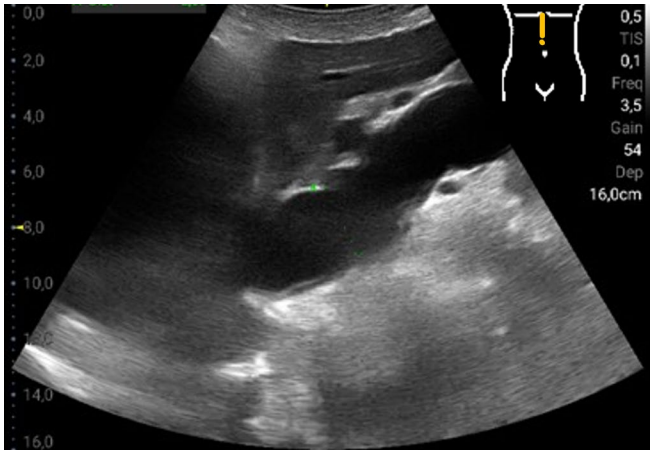

Fig. 2. *Sonographic image of a vena cava dilated to 27 mm obtained using the Youkey Q7. The patient's diuretic therapy was intensified*

Only 33/52 (63.5%) focal intra-abdominal lesions were detected with the Youkey Q7 (Fig. 2). With the exception of the pancreas, there were significant differences between the HEUS and HHUSD in the detection of focal organ lesions. Although further analysis of the false-negative diagnostic findings did not reveal evidence of malignancy, abdominal ultrasonography with HEUS cannot be replaced by HHUSD for the search of focal intra-abdominal lesions. In contrast to our results, Barreiros *et al.*[32] visualized 162/167 (97.0%) focal lesions using HHUSD compared with HEUS as the gold standard.

In detecting thoracic pathology, HHUSD showed a sensitivity of 84.6% compared with HEUS (Fig. 3). Among the false-negative findings, none were diagnostically or therapeutically significant. HEUS and HHUSD showed very good agreement in detecting pericardial effusion ($\kappa = 0.92$) as well as right ($\kappa = 0.90$) and left pleural effusion ($\kappa = 0.94$). HHUSDs are also useful for visualizing pericardial and pleural effusion in emergency medical settings[29,30]. In addition, Wastl *et al.*[30] showed that HHUSD is not inferior to HEUS in detecting reduced ejection fraction, wall motion abnormalities, and right heart strain. Further studies proved that pericardial and pleural effusions can be reliably diagnosed using HHUSD[36–38]. In the study by Graven *et al.*[38], the examinations were performed by inexperienced nurses who had completed a training period under the supervision of an experienced cardiologist before the start of the study.

With regard to the questions recommended by the EFSUMB that can be answered with HHUSD[19], our findings show that the portable ultrasound device is suitable for answering the following: the presence of pleural effusion (sensitivity: right 86.2% and left 90.9%, specificity: right 100% and left 97.8%), pericardial effusion (sensitivity 85.7% and specificity 97.4%) and urinary retention (sensitivity and specificity 100%). Sensitivity for aortic aneurysm detection was 100%, but only one case was diagnosed. In contrast, HHUSD is not suitable for the detection of gallbladder stones (sensitivity 75.0%, specificity 98.2%), dilated bile ducts (sensitivity 50.0%, specificity 99.2%), or hydronephrosis (sensitivity 50.0%, specificity 100%). Sensitivity for detecting free intra-abdominal fluid was only 72.7%, but all cases involved non-puncture-worthy fluid collections. For larger amounts of ascites, some of which required puncture, the portable ultrasound machine had a sensitivity of 95.8% in the study by Keil-Rios *et al.*[39].

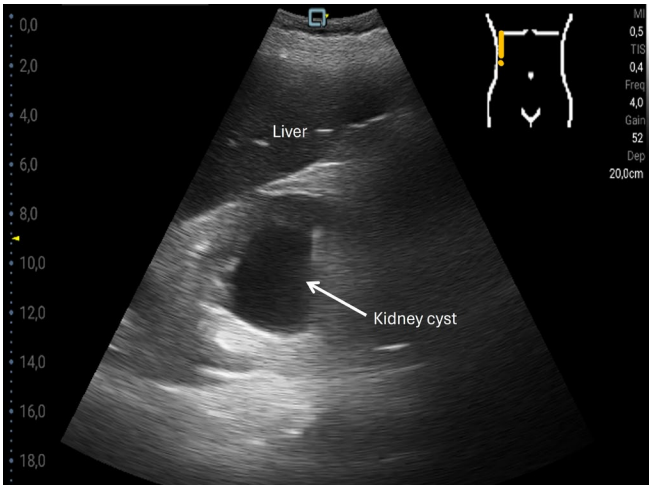

Fig 3. *Sonographic image of a right-sided renal cyst visualized with the Youkey Q7*

As a secondary criterion of the study, the duration of the investigation was determined for the HHUSD and HEUS in 46/120 patients. The average time was 3.18 minutes longer with the HHUSD. Similarly, in the work of Stock *et al.*[40], the time was longer on average with the HHUSD. However, the total examination time, which also took into account the transfer time of the device and start-up duration, was shorter with the HHUSD. Fischer *et al.*[41] compared the examination time of HHUSD and portable HEUS in the context of bedside ultrasound. The examination time with the portable ultrasound unit was significantly shorter at 15 ± 3 minutes (HEUS: 22 ± 4 minutes). The time advantage resulted from a shorter duration for start-up and transport of the ultrasound unit. The pure sonication time was not significantly different between the two devices.

Limitations of the study

This study has several limitations. It was designed to evaluate the benefit of routinely performed, symptom-independent abdominal ultrasonography in ICU patients. In the course of the study, 11 of 120 patients (corresponding to 9.2%) were examined with a targeted question due to gastrointestinal complaints or abnormal laboratory values, potentially influencing the results of the examination.

The study was conducted in a monocentric manner at an internal medicine intensive care unit in a hospital in central Germany. External validity is limited due to the specific internal medicine patient population, as well as the demographic and ethnic composition of the rural catchment area. Thus, the results cannot be directly generalized to intensive care patients in other hospitals. Further multicenter studies are needed for this purpose.

The study design is also a limiting factor. During patient recruitment, some selection is likely due to the dual role of the recruiter and investigator. Because patients were examined by only one investigator, no statement can be made regarding interobserver variability.

The poorer detection rate of thoracoabdominal pathologies in this study, compared with the above-mentioned comparative studies, can be attributed mainly to the examiner's limited experience. An experienced examiner might have detected a greater number of pathological findings with the HHUSD.

Within the study, the differences in detection rates between the two modalities can also be explained by the better spatial resolution of the HEUS, which makes it easier to identify patterns in B-mode imaging, especially for novices. The results suggest a better detection rate for pathologies that require high resolution for accurate detection (e.g., DHC enlargement, focal lesions of parenchymal organs in the abdomen). Conversely, there is strong agreement between the HEUS and HHUSD in the identification of conditions that are easy to recognize even with lower resolution (e.g., urinary retention, dilated vena cava). As an important prerequisite, image quality was comparable in both modalities, with slightly better performance in HEUS examinations.

The study did not provide sufficient evidence of a time advantage associated with the use of portable ultrasound devices. This is primarily due to the study design and the documentation of the study time in only about 40% of cases. To assess the potential benefit of

portable ultrasound devices in the intensive care setting, time and cost efficiency are important parameters in addition to diagnostic yield. This should be further investigated in future studies.

Since the present study was conducted in 2019, it is possible that technical advancements in HHUSD may lead to an underestimation of its current potential. While HEUS has also seen improvements, the rate of advancement is likely not as substantial.

Both examinations were performed by the same examiner with limited experience and under suboptimal examination conditions, which reflects typical real-world circumstances in an ICU, especially for the HHUSD. Using this strategy likely enhanced comparability, as using different investigators with varying skill levels could have introduced additional variability.

The investigator was a resident without specialist training, which possibly reflects again the real-world situation in an ICU. If an experienced investigator had performed the examinations, both machines would not have been comparable.

The aim of this study was to assess whether HHUSD findings could be improved by HEUS, thus allowing to estimate in real-world situations if HEUS is necessary after HHUSD in an ICU or emergency unit. In daily practice, one would not evaluate performing HHUSD after HEUS. If HEUS and HHUSD were regarded as equivalent methods, randomizing their sequence would be appropriate.

No definitive conclusions can be drawn from this study about the prognostic relevance of symptom-independent sonography in patients in the intensive care unit. Further prospective studies with a control group without sonography, as well as a follow-up period, are necessary to provide more robust data in this regard.

Conclusions and outlook

Based on the results of the study presented here, standard ultrasound examination in ICU patients appears justified, as diagnostic findings were detected in 13/120 (10.8%) and therapeutically relevant findings in 38/120 (31.7%) patients. Dilatation of the vena cava was the most common therapeutically relevant finding, which could also be reliably detected with the HHUSD. Routine abdominal ultrasonography detected pathological findings that would have been missed if only symptom-based focused sonography was performed.

With the HHUSD, only 33/52 (63.5%) focal intra-abdominal lesions were detected. Among the false-negative findings, four were diagnostically significant: one lesion of the liver, two lesions of the kidney, and one case of urinary stasis kidney. No therapeutically relevant findings were missed with the HHUSD. The use of HHUSDs is appropriate for the clarification of the following yes or no questions: dilatation of the vena cava, presence of urinary retention, prostatic enlargement, pleural or pericardial effusion, and signs of ileus. Contrary to the recommendations of the EFSUMB[19], based on the present findings, the question of dilated bile ducts, gallbladder stones, or hydronephrosis cannot be answered reliably enough with HHUSDs. Furthermore, HHUSDs are not appropriate for the detection of focal lesions. Although no significant difference was found between the HEUS and HHUSD in detecting focal pancreatic lesions, HHUSDs should not be used for addressing this question because of the small number of pancreatic lesions detected. Thus, HEUS examinations cannot be replaced completely by HHUSDs; however, if HEUS is not available, HHUSD is a viable – though not equivalent – alternative. The presence of symptoms could lead to the decision whether HEUS is necessary, as outlined in Tab. 1.

The advantage of HHUSD concerning space requirement and quick availability is currently partially tempered by problems concerning documentation and examination settings.

Routine, symptom-independent abdominal ultrasonography provided diagnostic and therapeutically relevant findings, as well as prognostically relevant additional information. In the case of incurable metastatic disease, for example, escalations of intensive care treatment (e.g., resuscitation or invasive ventilation) should be critically considered. Beyond a patient's general condition and the severity of the primary illness, these additional sonographic insights provide a valuable foundation for determining appropriate therapy limitations. Based on the findings of this study, it is to be concluded that patients in an internal medicine intensive care unit should receive timely abdominal ultrasonography regardless of the presence of symptoms in order to make diagnostic, therapeutic, and prognostic decisions. Abdominal ultrasonography can also be performed with HHUSDs if the general time pressure of an intensive care unit makes it necessary.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: AI, MD, CFD. Writing of manuscript: AI, MD, DW, KM, BH, CFD. Analysis and interpretation of data: AI, MD, CFD. Final acceptation of manuscript: AI, MD, DW, KM, BH, CFD. Collection, recording and/or compilation of data: AI, MD, CFD. Critical review of manuscript: AI, MD, DW, KM, BH, CFD.

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