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Simulation of Abdomen Sonography. Evaluation of a New Ultrasound Simulator

Simulation der Sonographie des Abdomens. Evaluierung eines neuen Ultraschall Simulators

Zusammenfassung

Studienziel: Zur Verbesserung der Ausbildungsqualität in der Sonographie entwickelten und evaluierten wir einen Simulator für die Sonographie des Abdomens. **Methode:** Elf Assistenzärzte des Zentrums Innere Medizin, die eine 4- bis 12-monatige Sonographieausbildung erhalten hatten, führten bei 5 konsekutiven Patienten und bei 5 Simulatorfällen eine Sonographie des rechten Oberbauches durch. Die Befundkorrektheit und der Zeitbedarf der jeweiligen Untersuchung wurden gemessen. Auf einer visuellen Analogskala beurteilten die Probanden die subjektive Sicherheit in der Befundinterpretation und das Handling des jeweiligen Gerätes. **Ergebnisse:** Die Assistenzärzte erkannten am Patienten 75% (Standardfehler SEM 9%) aller vorhandenen pathologischen Befunde, am Simulator 71% (SEM 8%). Der minimale Unterschied erwies sich im gepaarten zweiseitigen t-Test als nicht signifikant (p = 0,15). Schwerwiegende Befunde wurden nicht übersehen. Die Untersuchung beanspruchte beim Patienten 10,57 min (SEM 3,25 min), am Simulator 9,59 min (SEM 2,98 min). Der Unterschied war nicht signifikant (p = 0,53). Auch die subjektive Sicherheit in der Sonographiebefundung war am Sonographiegerät mit 68% (SEM 6%) und am Simulator mit 64% (SEM 12%) nicht signifikant unterschiedlich (p = 0,39). Lediglich die Beurteilung des Handlings fiel mit 61% (SEM 12%) am Simulator signifikant schlechter aus (p = 0,008) als am Sonographiegerät mit 74% (SEM 7%). **Schlussfolgerung:** In der ersten direkten cross over Vergleichsstudie zwischen realer Sonographie am Patienten und am Simulator konnten wir zeigen, dass der von uns entwickelte und evaluierte Simulator die reale Patientenuntersuchung zuverlässig und reproduzierbar simuliert.

Abstract

Aim: We developed and evaluated a simulator for the sonography of the abdomen in order to improve the teaching quality in sonography training. **Method:** Eleven medicine residents who had received 4 to 12 months full time sonography training performed ultrasound examinations of the right upper quadrant in 5 consecutive patients and in 5 simulator cases. The correctness of their findings and the time required for the examinations were measured. The subjective confidence in their findings and the handling of the ultrasound machines were rated on a visual analogue scale. **Results:** During patient ultrasound examination 75% (SEM 9%) of all pathologic findings were recognized by the residents, whereas 71% (SEM 8%) of the pathologies of the simulator cases were found. This minimal difference was not significant in the paired, two sided t-test (p = 0.15). Severe pathologies did not escape detection. The time required for patient examination (10.57 min, SEM 3.25 min) was not significantly different (p = 0.53) to the time required for the simulator cases (9.59 min, SEM 2.98 min). The subjective confidence in the sonographic findings did not differ significantly (p = 0.39) between the real patient situation (68%, SEM 6%) and the simulation (64%, SEM 12%). Only the handling of the ultrasound machines was judged to be significantly better (p = 0.008) than the simulator (74%, SEM 7% vs. 61%, SEM 12%). **Conclusion:** In this first direct cross over comparison between real patient sonography and simulator based scanning we proved that the simulator we developed simulates the real patient examination reliably and reproducibly.

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Key words
Ultrasound · simulator · training · clinical study · quality management

Introduction

The sonography of the abdomen is one of the most important imaging methods in medicine [1]. Sonography modifies the initial clinical diagnosis in up to 52% with a resulting change of treatment in up to 46% of the ultrasound examinations [2]. Furthermore, sonography increases diagnostic certainty [3]. However, the correctness and the diagnostic impact of a sonographic examination are very dependent on the quality of the ultrasound machine used [4] and the education and experience of the examiner [5]. Therefore the quality of sonography training becomes crucial in order to avoid "verifying" ultrasound examinations by computed tomography or magnetic resonance imaging and ultimately in order to limit healthcare expenditures by quality control [6]. The skill of the ultrasound examiner is well known to correlate positively with the number of scans performed [4,7,8]. In addition, the importance of pathologic findings during ultrasound training was demonstrated recently [9]. However, apart from minimal numbers of ultrasound scans to be performed during residency, there is considerable variability of sonography training in Germany [6], Europe [10] and abroad [11,12]. Furthermore, the quality of ultrasound education varies very much [11], which can partly be explained by differing sonographic as well as didactic skills of the educators [13]. Finally no mandatory, standardized quality control exists so far [6]. After all, widespread implementation of the three level concept of ultrasound quality, education and credentialing, which is recommended by the World Health Organization [14] and the European Federation of Societies for Ultrasound in Medicine and Biology [15], will improve ultrasound quality.

The apparent difficulty to establish an ultrasound training meeting most of the above mentioned requirements is explained by numerous factors. Different quantities and qualities of specific pathologic findings result from distinct patient collectives. Furthermore, in an environment of rigorous cost-cutting efforts in health care, the time available for sonography training becomes more and more scarce, as well for the clinical sonography unit as for the physician in training [6]. Finally, scanning is a complex motorical process requiring a good knowledge of the three dimensional anatomy in order to position the ultrasound transducer optimally, which cannot be taught well by two dimensional pictures in textbooks showing "gold-standard" visualization [16]. Other subspecialties are trying to overcome variabilities in patient collectives, time constraints of clinical routine and deficits in standardized quality control by simulation [17]. Simulators are being successfully used in anaesthesiology to simulate resuscitation [17], ventilation [18] and anaesthesia [19], as well as in medicine to simulate cardiac catheterization [20] and endoscopy [21,22]. Most of the benefits of simulation can be deducted from aviation as the most familiar example, utilizing flight simulators for improving training and standardizing recertification [17]. Finally, flight simulators have been linked to a reduced number of accidents [23].

Recently, ultrasound simulators have been developed. They were shown to be equally effective compared to traditional hands-on patient models in teaching surgery residents focused abdominal sonography for trauma (FAST) [24,25]. Moreover, an ultrasound simulator was used to assess sonography skills of radiology residents before taking overnight call [26]. Finally, an ultrasound simulator has been shown to simulate antenatal sonography during pregnancy well [16].

However, to the best of our knowledge, no direct cross over study with the real patient situation in order to assess the quality of the simulator used has been done so far. We do believe that this principal parameter has to be determined before evaluating substitute parameters such as suitability for teaching purposes or the like. Therefore we evaluated a simulator we had developed for the sonography of the abdomen in a direct cross over study.

Subjects and Methods

Eleven physicians belonging to the department of Internal Medicine of the Hannover Medical School, who had previously received 4–12 months all day ultrasound training in the local ultrasound unit, volunteered to participate in the study.

They performed routine ultrasound examinations of the right upper abdominal quadrant for 5 consecutive random patients of the ultrasound unit and were blinded to the results of previous imaging studies and the medical history. The numerous pathologic findings of the patient population (Table **1**) included level 1–3 ultrasound pathology [15]. The pathologic spectrum encountered in the real patient situation was matched by the 5 simulator cases (Table **1**, Fig. **1–2**), which the volunteers scanned in random order. Starting the study with the real patient scans or the simulator scans was assigned in random sequence. The right upper abdominal quadrant ultrasound examinations of the patients included up to 7 distinct pathologies whereas the simulator cases contained up to 4 different pathologic findings. The patient examinations as well as the simulator cases were checked by either JB or MG, who both hold the highest DEGUM (German society for ultrasound in medicine) ultrasound certificates (Seminarleiter). The correctness of the ultrasound examinations and the time needed for each scan were measured. The volunteers scored the subjective confidence in their sonographic findings and the handling of the ultrasound machines or the simulator respectively on a visual analogue scale. On the visual analogue scale used, 100% represented extremely good and 0% meant extremely bad.

Statistical analysis was performed using the paired two-sided t-test.

Table **1** Pathologic findings of the patient population and the simulator cases

	Ultrasound pathology of the patient population examined by one physician	*Ultrasound pathology of the simulator cases examined by each physician*
physician 1	liver cirrhosis, steatosis hepatis, hepatomegaly, status post left sided hemi-hepatec-tomy, liver congestion, portal vein dilatation, transjugular portosys-temic shunt, lymph node enlargement in porta hepatis, intra- and extrahepatic cholestasis, cholangitis, aerobilia, cholecystolithiasis, kidney cysts, kidney calci-fication, pericardial effusion, pleural effusion, little and large amount of ascites	liver cirrhosis, liver cysts, intrahepatic echino-coccus cyst, liver hemangioma, status post right sided hemihepatec-tomy, intra- and extrahepatic cholestasis with and without bile duct stents, lymph node enlargement in porta hepatis, cholecystolithiasis, pancreatic pseudocyst, chronic panc-reatitis, little ascites
physician 2	liver cirrhosis, hepatomegaly, liver tumour, liver cysts, hepaticojejunostomy, intra- and extrahepatic cholestasis, cholangitis, cholecystolithiasis, gall bladder sludge, status post cholecystectomy, pancreatic duct dilatation, aortic sclerosis, pericardial effusion, little ascites	
physician 3	liver cirrhosis, steatosis hepatis, portal vein dilatation, reopened umbilical vein, lymph node enlargement in porta hepatis, aerobilia, hemobilia, extrahepatic cholestasis, cholecystolithiasis, gall bladder sludge and polyps, hypertensive gastropathy, splenic vein dilatation, chronic pancreatitis, pancreatic pseudocyst, large amount of ascites	
physician 4	liver cirrhosis, steatosis hepatis, status post right sided hemihepatectomy, liver con-gestion, reopened umbilical vein, liver hemangioma, hepatocellular carci-noma, hepa-ticojejunostomy, aerobilia, status post cholecystectomy, kidney cyst, little ascites	
physician 5	liver cirrhosis, liver metastasis, liver cyst, liver hemangioma, transjugular portosys-temic shunt, intrahepatic cholestasis, aerobilia, cholecystolithiasis, cholecystitis, gall bladder sludge, splenic vein dilatation, pancreatic pseudocyst, kidney stone, little ascites	
physician 6	steatosis hepatis, liver cirrhosis, liver cyst, portal vein dilatation, aerobilia, cholangitis, intra- and extrahepatic cholestasis, hepaticojejunostomy, lymph node enlargement in porta hepatis, status post cholecystectomy, gall bladder polyps, acute pancreatitis, pleural effusion, little ascites	
physician 7	liver cirrhosis, steatosis hepatis, hepatomegaly, liver congestion, liver tumour, liver cyst, hepaticojejunostomy, intrahepatic cholestasis, bile duct stent, cholangitis, lymph node enlargement in porta hepatis, status post cholecystec-tomy, cholecystolithiasis, splenic vein dilatation, pleural effusion	
physician 8	liver cirrhosis, hepatomegaly, intrahepatic cholestasis, status post right sided hemihepatectomy, transjugular portosystemic shunt, portal vein dilatation, liver metastases, cholangitis, bile duct stent, hepaticojejunostomy, status post cholecystectomy, cholecystolithiasis, aortic sclerosis, pancreatic pseudocyst, kidney cyst, little ascites	
physician 9	liver cirrhosis, steatosis hepatis, portal vein dilatation, reopened umbilical vein, lymph node enlargement in porta hepatis, gall bladder polyp, cholecystolithiasis, acute pancreatitis, chronic pancreatitis, pancreatic duct dilatation, little ascites	
physician 10	liver cirrhosis, steatosis hepatis, status post left sided hemihepatectomy, liver heman-gioma, liver tumour, intrahepatic cholestasis, hepaticojejunostomy, aerobilia, cholan-gitis, status post cholecystectomy, gall bladder polyps, cholecystolithiasis, pancreatic pseudocyst, pancreatic tumour, kidney cyst, adrenal tumour, little ascites	
physician 11	liver cirrhosis, steatosis hepatis, status post left sided hemihepatectomy, portal vein thrombosis, liver tumours, hepatocellular carcinoma, cholangitis, status post chole cystectomy, gall bladder sludge, splenic vein dilatation, kidney cyst, little ascites	

Fig. 1 Simulator image showing a liver hemangioma and some of the simulator features.

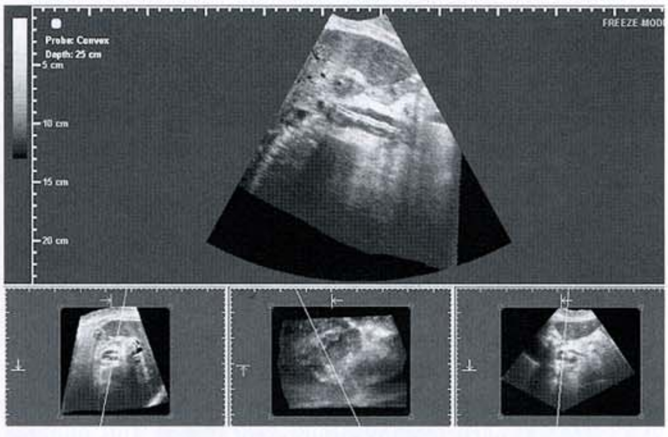

Fig. 2 Simulator image showing extrahepatic bile duct dilatation and an occluded plastic stent. Furthermore, in order to demonstrate the simulator's mode of operation, additional cuts through the 3-dimensional ultrasound volume are presented.

Fig. 3 The ultrasound simulator, consisting of a powerful computer, a life-like mannequin with an integrated electromagnetical localisation unit and a 3-dimensional sensor inside the dummy transducer.

The ultrasound machines utilized in this study were the Esaote AU5 Harmonic (Esaote, Italy) and the Toshiba Aplio (Toshiba, Japan), both with 3.5 MHz transducers.

The ultrasound simulator (Sonofit GmbH) has been described in detail elsewhere [16]. In short, the ultrasound simulator consists of a powerful computer, a life-like mannequin with an integrated electromagnetical localisation unit and a 3-dimensional electromagnetic sensor inside the dummy transducer (Fig. **3**). In order to acquire ultrasound cases for the simulator, the 3D electromagnetic sensor is attached to the transducer of the ultrasound machine. The electromagnetical localisation unit is placed next to the patient. For data acquisition, a long sweep of the abdominal quadrant of interest is performed and digitally recorded by the simulator. Parallel to the sweep, the exact position of the transducer inside the electromagnetic field generated is calculated continuously and stored. In a subsequent calculatory process the digital data of the ultrasound sweep and the transducer position are combined and a three dimensional ultrasound volume is generated. Finally, the 3D ultrasound volume is positioned anatomically correct inside the life-like mannequin. The Siemens Sonoline Elegra (Siemens, Germany) was used for case acquisition. 3D ultrasound volumes were acquired in photopic mode (Siemens, Germany), combined with tissue harmonic imaging.

For simulating ultrasound examinations at the simulator, the calculatory process described above is reversed. The position of the dummy transducer scanning the virtual patient is located inside the electromagnetic field generated around the mannequin. The simulator reconstructs, using the 3D ultrasound volume chosen as a blueprint, the B-mode images corresponding to the present dummy transducer position in real time. Similar to a real ultrasound machine, depth and gain can be varied, images can be frozen and measurements can be performed (Fig. **2**). By just looking at the screen, bystanders cannot tell whether a mannequin at the simulator or a real patient is scanned.

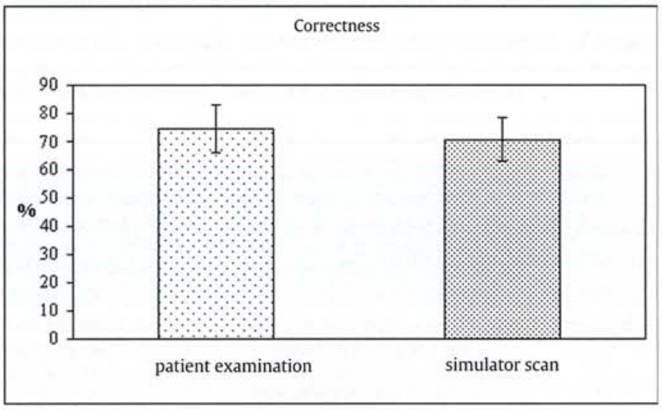

Fig. **4** Correctness of patient ultrasound examination and simulator scan, given in mean %, ± SEM, difference not significant.

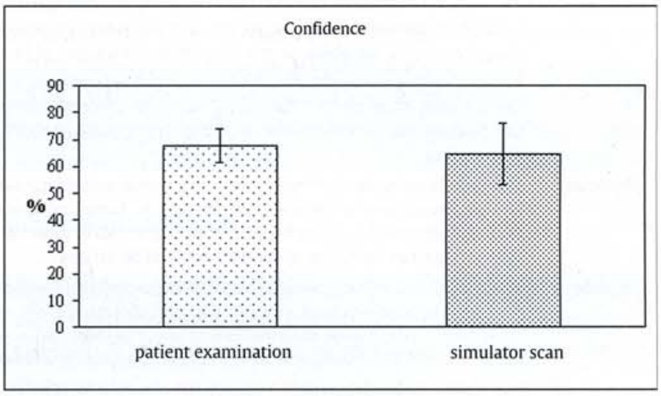

Fig. **5** The volunteers subjective confidence in the sonographic findings, given in mean %, ± SEM, difference not significant.

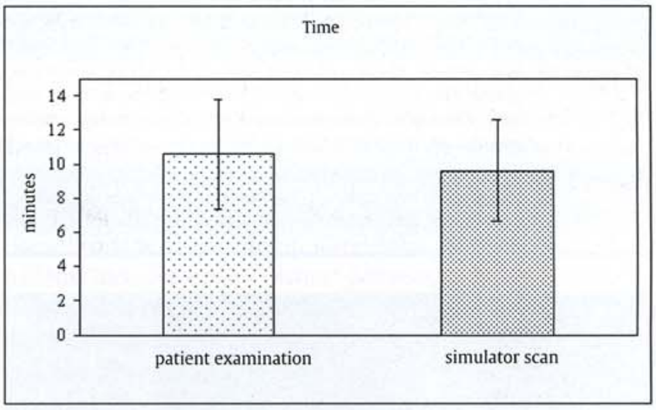

Fig. **6** Length of the real ultrasound and simulator case examination time, given in minutes, ± SEM, difference not significant.

Results

In our study, the 11 internal medicine residents recognized 75% (SEM 9%) of all pathologic sonographic findings in the 5 consecutive patients. Scanning the 5 simulator cases, they identified 71% (SEM 8%) of the pathologies present (Fig. **4**). This minimal difference was statistically insignificant ($p = 0.15$). Only minor and no severe pathologies were overlooked, such as beginning liver cirrhosis or discretely enlarged lymph nodes in the porta hepatis. No tumours were missed on ultrasound examination, neither in the patient situation nor at the simulator. The subjective confidence in the sonographic findings did not differ significantly ($p = 0.39$) between the real patient situation (68%, SEM 6%) and the simulation (64%, SEM 12%) (Fig. **5**). Furthermore, the time required for scanning the right upper quadrant was similar ($p = 0.53$) comparing the real patient examination (10.57 min, SEM 3.25 min) with the simulator scans (9.59 min, SEM 2.98 min) (Fig. **6**).

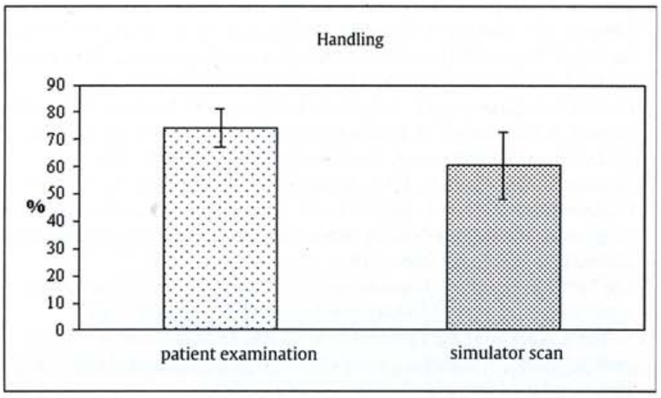

Fig. 7 Handling of the ultrasound machine and the simulator, given in mean %, ± SEM, 100% representing extremely good and 0% meaning extremely bad, difference statistically significant.

The only statistically significant difference ($p = 0.008$) we found was in handling, the ultrasound machines were judged to be better than the simulator (74%, SEM 7% vs. 61%, SEM 12%) (Fig. 7).

Discussion

This study is the first cross over study between the real patient ultrasound examination and simulator scans. The correctness, the time requirements and the subjective confidence in the examiners' findings were similar comparing the real patient ultrasound examination and scans performed at the simulator. Both the real patient scans and the simulator scans included a wide variety of level 1–3 ultrasound pathology [15] of the right upper quadrant. The results of our study above prove our simulator to simulate the abdominal ultrasound examination reliably and reproducibly. Having shown the extremely realistic simulation capabilities of the simulator we developed, the simulator will help to overcome many of the problems of ultrasound education mentioned in the introduction. With the means of the simulator, ultrasound trainees will be able to practice on similar, standardized pathologies and will become independent of the present limitations of the quantity and quality of pathologic findings, hitherto dictated by the respective patient collective. For this reason, the ultrasound simulator will be of good use not only for the beginner, but it will also facilitate continuing medical education for the advanced examiner, wanting to improve ultrasound skills on more seldom pathologies. Furthermore, the simulator for the first time offers the possibility of objective, standardized certification and recertification procedures, ultimately ensuring quality control and health care cost reduction in ultrasound. Linking the ultrasound simulator to haptic elements, even interventions might be practiced on the simulator in the future, similar to virtual colonoscopy [21] or interventional cardiology [20].

However, the present generation of abdominal ultrasound simulators still faces some technical limitations. Even though we did not further specify in our study, we suspect that the somewhat worse ranking in handling of the simulator is the result of a suboptimal image quality of the simulator when scanning in an angle of approximately 90° to the angle of image acquisition. In order to solve this slight problem, we constantly work on further improvements of the soft- and hardware of the simulator. At present, only one abdominal quadrant can be scanned at a time and colour duplex examinations are not yet possible. Moreover, the 3 dimensional ultrasound volumes are acquired in inspiration hold, giving the examiner at the simulator no chance to improve the examination conditions by virtual inspiration maneuvers of the mannequin. Finally, the acquisition of new 3D ultrasound volumes is time consuming and technically difficult, delaying the building of comprehensive simulator case libraries, which we work on none the less.

At last, our preliminary experience with the use of our abdominal ultrasound simulator in beginner and advanced level ultrasound training courses is very encouraging. The course participants were very happy to gain experience with clearly defined ultrasound pathologies with or without immediate supervision. In order to improve simulator teaching without immediate supervision, we meanwhile incorporated clinical case information and a guide function into the simulator, leading the trainee to optimal ultrasound visualisation of the pathology studied. However, we strongly recommend this new educational device to be thoroughly evaluated in the training environment before its widespread use.

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