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Ultrasound simulators: experience with the SonoTrainer and comparative review of other training systems

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ABSTRACT

Ultrasound has become indispensable in prenatal diagnosis. Ultrasound training, however, still lacks proper quality assessment and control. Moreover, most fetal anomalies which must be diagnosed during pregnancy are extremely rare. Ultrasound simulators could provide an opportunity to overcome this dilemma. This review summarizes the potential benefits of simulator-based ultrasound training, briefly describes the properties of a variety of ultrasound simulators that have been developed for various applications including prenatal diagnosis, and presents the SonoTrainer sonography simulation system which makes it possible to run a real-time simulation of a complete prenatal ultrasound examination. We evaluated the system for the training of first- and second-trimester screening for both normal and pathological findings and found that physicians who received theoretical training and were additionally trained with the simulator (T + S) significantly improved their skills in measurements of nuchal translucency thickness (NT) and crown–rump length (CRL) as compared with colleagues who only underwent theoretical instruction (T) [mean ± SD NT deviation: 0.31 ± 0.1 mm (T + S) vs. 0.62 ± 0.2 mm (T), $P < 0.05$*; mean ± SD CRL deviation: 1.48 ± 2.0 mm (T + S) vs. 3.27 ± 2.5 (T),* $P < 0.05$*]. Simulator-based training enabled physicians to diagnose rare fetal anomalies in the second trimester with a sensitivity of 86% and a specificity of 100%. In a study in which second-trimester scans including fetal anomalies were presented to physicians, 96% of the participants subjectively estimated their training effect as being good. We therefore conclude that simulator-based training would provide an ideal educational tool to test, improve and monitor a physician's or technician's ultrasound skills in detecting fetal anomalies.*

INTRODUCTION

Prenatal ultrasound has become the central, most widely used tool in screening for fetal abnormalities. Non-invasiveness, immediate results and many other advantages have contributed to it being the technique of choice. It is a safe diagnostic tool and can identify many major structural anomalies[1,2].

Although ease of use is greater compared with other diagnostic techniques, the sensitivity of detecting fetal anomalies is far below 100% and depends to a major extent on the examiner's training and experience. In fact, multicenter studies from the early 1990s demonstrated that the introduction of ultrasound screening into prenatal care did not lead to a reduction in perinatal mortality and morbidity[3,4].

The first problem is that fetal anomalies occur with an incidence of only 2% (all major anomalies) to 5% (all minor anomalies) of all pregnancies[5–8]. Although these overall rates are comparably high, the specific anomalies are extremely rare under routine screening conditions and may be seen only once or not at all in a doctor's lifetime. At present training follows the classical two-stage model: theoretical knowledge comes with using the major textbooks in the field; practical knowledge (experience) is only generated by performing ultrasound examinations on as many patients as possible. The second problem, however, is the conditions under which ultrasound examinations in patients are performed: unlike the more 'anonymous' methods, such as X-ray, nuclear magnetic resonance imaging, or computed tomography, ultrasound produces immediate results. Since the patient

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is present and time for reflection is short, physicians may tend to down-play suspicious observations. The third problem is that ultrasound, unlike the techniques named above, is a less standardized and more subjective method that depends to a major degree on the training and experience of the individual examiner. Additionally, ultrasound interpretation is highly dependent on the movements of the ultrasound probe. The examiner's movements almost generate a virtual three-dimensional (3D) impression; single pictures, however, are difficult to interpret. This aspect explains why it is very hard to obtain second opinions from colleagues when there are suspicious or questionable ultrasound findings: either the colleague repeats the scan completely or, rarely, will view the scan by means of telemetry. In the latter case, this colleague will have difficulties in achieving the 3D 'feeling' that we judge as being very important.

Despite these limitations, ultrasound has become more and more important. With impressive improvements in ultrasound image quality it is no surprise that patients demand 100% certainty in their diagnosis whether or not this can be achieved.

In fact, more and more lawsuits in cases of undetected fetal anomalies point to the need for further training and qualification of physicians performing prenatal diagnosis by ultrasound. At present, physicians cannot be trained sufficiently or keep their achieved skills other than in highly specialized prenatal centers, and even at these centers training is limited[9,10]. Diagnosis of an anomaly is a very stressful situation for both the patient and the doctor. Under these conditions, it is not possible to have the ultrasound scans repeated by an unlimited number of different physicians who would like to 'see' the anomaly. However, practically the physician must diagnose fetal anomalies that he or she has never seen before. Osteogenesis imperfecta, a rare anomaly that is difficult to diagnose (incidence 1 : 29 000 to 1 : 64 000 depending on type; hypomineralization (very subjective parameter), and degree of limb shortening (often mild)), is only one example of a variety of fetal malformations. However, once a physician has seen an anomaly he will naturally recognize and diagnose it more easily if it occurs in another patient.

ULTRASOUND SIMULATORS

One way to improve the ultrasound training of physicians and ultrasound technicians could be standardized, quality-controlled training using ultrasound simulators. In the past decade several simulator systems have been developed (Table 1). However, none of these systems has found widespread distribution so far. Additionally, information on the systems themselves and reproducible data on their practical use or results of clinical trials are sparse.

First experiences with ultrasound simulators in prenatal diagnosis were reported by Lee *et al.*[11] These authors demonstrated improvements in orientation, especially when performing fetal echocardiography. Other studies[12,13] described improved software algorithms to enable interactive examination scenarios including Doppler ultrasound simulation. Smith *et al.*[14] found that ultrasound simulators can also be used for training in invasive procedures such as amniocentesis. More recent studies on trauma simulation systems demonstrated that the learning effect by using simulators is similar to the learning effect when examining real patients[15–17].

Of the simulator systems summarized in Table 1, only two have developed simulations of fetal scans including fetal anomalies. Additionally, very little has been published on the properties of the different systems. Most of the systems seem to be designed as regular computer programs. However, a simulator needs to provide a simulation as close to reality as possible.

For this purpose, our group developed and tested the SonoTrainer ultrasound system, an ultrasound simulator that displays normal and abnormal fetal scans under real-time conditions[9]. It is used with the full-torso mannequin, designed for transvaginal examinations for gynecology and obstetrics as well as breast scanning. The mannequin has a soft, pliable, rubber surface that covers a foam belly representative of a late-first or early-second trimester pregnancy, and allows the performance of abdominal biopsy and amniocentesis. Education modules are available for transvaginal, gynecological, obstetric, abdominal and carotid Doppler examinations. We have also recently developed a module for fetal echocardiography, providing full motion of the fetal heart.

Description of the SonoTrainer training system: data acquisition, data processing, and ultrasound simulation

The data acquisition system contains a 3D sensor, which seizes instantaneous virtual position data transmitted to an image-processing computer. The computer evaluates the location and position of the transducer and the related (two-dimensional (2D)) slice-sections. The system inserts the acquired slice-sections of the active transducer to form 3D images and displays these slice-sections by means of 2D images on the monitor. As a result, the system displays visually the images that correspond with the instantaneous position of the simulated transducer. A similar approach has been used by others[12,13,18–21].

Using a 'life-size' dummy, the system simulates the entire procedure of prenatal ultrasound scanning in a realistic, interactive and real-time manner. The system provides measurement functions with high accuracy according to medical certification standards for distance, area, volume and angles. This feature enables the integration of biometry into training tasks. Also, the selection of transducers and penetration depth can be made similar to when using a real ultrasound scanner.

Between 1 June 2000 and 31 December 2000, 3D data from 115 normal fetuses and 29 fetuses with major anomalies were acquired from pregnant women attending the Division of Prenatal Diagnostics, Department of Obstetrics and Gynecology (Hannover Medical School, Hannover, Germany) and processed for display by the ultrasound simulator. All cases were collected using the

Table 1 Different ultrasound simulation systems, their origin, data acquisition mode, properties, references, years of publication, number of references in the field of prenatal diagnosis, and applications

Simulator	*Development and production*	*Data acquisition*	*Properties*	*Number of references (years of publication), number of references referring to prenatal diagnosis*	*Clinical applications*
UltraSim	MedSim Ltd. Kfar Sava, Israel	3D scans from patients	Realistic using a dummy, real-time, interactive, acceptable image quality	7 (1997–2002)[12,13,16,17,27–29], none	Gynecology (abdominal, transvaginal, breast), obstetrics (1st trimester, 2nd trimester), internal medicine (abdomen)
UltraTrainer	Fraunhofer Institute for Manufacturing Engineering and Automation, Stuttgart, Germany	NA	No data available	1 (1998)[30], none	Not specified
Virtual Echographic System	Laboratoire TIMC-IMAG, La Tronche, France	NA	No data available	1 (1996)[31], none	Unknown
VirUS	Department of Medical Physics and Bioengineering, St. George's Hospital, London, UK	Total simulation mimicking tissues (but based on original fetal images)	Interactive: gain and time-gain, compensation can be adjusted before measurements are taken	1 (2003)[26], 1	Quality assessment and training only: evaluation of interoperator and intraoperator repeatabilities (example: nuchal translucency measurement), learn to adjust gain and time–gain compensation in a standardized manner
EchoComJ, further developed to EchoComJ2	Fraunhofer Institute for Applied Information Technology, Schloss Birlinghoven, Sankt Augustin, Germany	3D scans from patients	Realistic using a dummy, operated by a trainee, real-time, interactive	3 (1995–2000)[18–20], none	Adult echocardiography
SONOSim3D	Polytechnical University of Stralsund, Medical Imaging and Computer Graphics Lab, Fachhochschule Stralsund, Fachbereich Elektrotechnik und Informatik, Stralsund, Germany	3D scans from patients	PC-based, interactive, real-time (including zoom-pan, contrast-brightness manipulation, switching between curved and linear array transducer geometry)	1 (1998)[21], none	Not specified
SonoTrainer	Sonofit GmbH, Stadecken-Elsheim, Germany	3D scans from patients	Realistic using a dummy, high image quality, real-time, fetal echocardiography including heart movements	4 (2001–2003), 3[9,23,32]	Obstetrics (1st trimester, 2nd trimester, major and minor anomalies, fetal echocardiography), gynecology (abdominal, transvaginal, breast), internal medicine (abdomen)

3D, three-dimensional; NA, not available.

3D ultrasound tracker (Medcom GmbH, Herschbach, Germany) and scans were performed by the same sonographer (A.S.).

Image quality of the SonoTrainer ultrasound simulator as judged by physicians

Twenty-four physicians were presented with SonoTrainer ultrasound simulations and asked to rate the image quality as being 'good', 'moderate' or 'bad'. Of the 24, 80% judged the image quality to be good, 20% judged it moderate and none judged it as being bad. Additionally, 96% subjectively judged their training effect with the simulator as being good, 4% as moderate and none as bad. All 24 physicians taking part in the study supported the idea of introducing simulator-based training into clinical practice.

Training method for first-trimester screening

To evaluate the effectiveness of the SonoTrainer ultrasound simulator as a training method for first-trimester screening we used this novel instrument in a study in which 45 certified obstetricians took part[22,23]. It is well known for nuchal translucency thickness (NT) measurements that interoperator repeatabilities are rather low. Pajkrt *et al.*[24] found a repeatability coefficient of ± 0.88 mm, while Pandya *et al.*[25] reported one of ± 0.62 mm. To investigate the potential benefits of simulator-based training, 24 of the 45 physicians underwent only theoretical training in the measurement of NT and crown–rump length (CRL), and 21 were additionally trained using the ultrasound simulator. NT and CRL were then measured in nine pregnant volunteers during the first trimester. For each obstetrician taking part in the study we determined the mean absolute deviations from measurement standards set in advance by two sonographers highly experienced in first-trimester screening and fully certified by The Fetal Medicine Foundation (http://www.fetalmedicine.com). For NT and CRL[22,23], the absolute deviations from the defined standards were significantly lower in the group of obstetricians who were trained both theoretically and using the ultrasound simulator (T + S) compared with the obstetricians who only received theoretical instruction (T) (Table 2).

Based on these findings, we conclude that the ultrasound simulation system significantly improves an examiner's skills to determine NT and CRL accurately during a first-trimester ultrasound examination and may therefore help to reduce the number of false-positive and false-negative screening results. Similar findings were reported in a recent paper published by Newey *et al.*[26] when they used a PC-based virtual ultrasound scanner. In their study the interoperator repeatability was ± 0.41 mm at a confidence level of 95%.

Training method for second-trimester screening

In a small prospective study, seven specialists in obstetrics and gynecology were asked to evaluate 10 ultrasound simulations each; eight were normal scans and two were scans from abnormal fetuses (one gastroschisis, one cystic adenomatoid lung malformation).

Five of the seven specialists identified the two fetuses with abnormalities and two recognized only one fetus with an abnormal ultrasound scan. None of the normal fetuses was judged as being abnormal by any of the specialists. Therefore the sensitivity (detection rate) in this experiment was 86% and the specificity was 100%[9] (Table 3).

Table 2 Differences in first-trimester screening quality after theoretical instruction with and without additional simulator-based ultrasound training

	Theoretical and simulator-based training	*Theoretical training only*	P
NT (mean ± SD deviation (mm) from gold standard)	0.31 ± 0.14	0.62 ± 0.23	< 0.05
CRL (mean ± SD deviation (mm) from gold standard)	1.48 ± 2.0	3.27 ± 2.48	< 0.05
Mean duration per examination (s)	450	895	< 0.05

CRL, crown–rump length; NT, nuchal translucency thickness.

Table 3 Detection rates of fetal anomalies presented by the simulator ($n = 70$ simulations)

	Finding (n)		
	Normal	*Abnormal*	*Total* (n)
3D-Simulation			
Normal	56	2	58
Abnormal	0	12	12
Total	56	14	70

SUMMARY

Our novel ultrasound simulation system gives the opportunity to train in ultrasound under real-time conditions in a realistic setting. The system provides all measurement functions (distance, area, volume, angle). Moreover, probe settings and depth as well as other parameters can be changed *ad libitum*, comparable to a real ultrasound machine.

Ultrasound simulators with which physicians could be trained to diagnose fetal anomalies independent from a time schedule and independent from doctor–patient interaction could help to increase the detection rates of fetal anomalies. Recently developed simulators represent a new era in ultrasound education with complete, virtual examination scenarios and comprehensive teaching aids.

Ultrasound simulators today can simulate almost every imaginable ultrasound examination without the need for patients or hired models, and can be used to train new and advanced users to recognize abnormalities and pathological events. Moreover, ultrasound simulators can be used to improve qualitative and quantitative diagnostic techniques and knowledge, and can be adapted to any teaching situation. Furthermore, they provide the possibility to quantify the training effect and the quality of teaching in a real-time situation.

Further studies are needed as soon as possible to improve the real-time properties of ultrasound simulators in general and to evaluate the advantages of simulator-based training, certification and quality assessment for prenatal diagnosis.

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