Simulated Medical Ultrasound Trainers A Review of Solutions and Applications

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Abstract: Ultrasound is one of the most widely employed real-time diagnostic imaging modalities in modern medicine. To use it efficiently, and to correctly interpret the images, the medical staff needs to acquire sophisticated skills. In this article, a review is provided on the devices and methods of modern ultrasonography training employing high-end information technology tools. It spans from the most critical moments, examination, to image-based training methods. Hardware and software based solutions are introduced along their current limitations. A comprehensive overview is provided about the most popular ultrasound simulators based on a common set of criteria, including their basic features, simulation methods, training concept and the supported scanning protocols. Tutors shall be able to make better informed decisions based on the enlisted characteristics of the various systems. The principles of simulation methods and techniques are also discussed in details along with the challenges of the field.

Keywords: medical imaging; ultrasound diagnostics; ultrasound simulation & training

1 Introduction

Medical ultrasound (US) has quickly gained popularity as a primary diagnostic imaging modality, since it is non-invasive and widely available. It played a major role in the rapid advancement of Computer-Integrated Surgery [1]. The US devices developed in the last years are getting smaller and more portable, relying on revolutionary multi-transducer matrices and crystal arrays; however their usage, and especially the interpretation of the images still relies heavily on the personal qualities of the human sonographer. The necessary skills require solid routine gained through extensive, hands-on training. Consequentially, during the basic medical doctoral (M.D.) education, and especially during the US practitioner training, it has utmost importance to acquire the necessary skills and experience in a controlled environment, to allow credentialing in a comparable manner. During regular examinations, there are specific, important US protocols, which are inconvenient to perform on humans e.g., the transthoracic echocardiography (TTE) or the transesopageal echocardiography (TEE). In such cases, the use of US simulators is recommended, and they allow the sonographers to focus on efficient tasks execution.

Medical US was originally developed to explore and study the anatomy and function of human organs. However, this imaging technique can also be applied for instrument tracking and as a guidance tool in a wide range of interventions [2–4]. More recently, US has been successfully employed for treatment as well, especially with the application of High-Intensity Focused Ultrasound (HIFU) [5].

The first US examinations were performed in the early 1970s, when the underlying technology allowing to detect the reflected ultrasound waves from internal human organs has become affordable. Over the years, the field of US imaging has evolved rapidly, whereupon this modality has become one of the cheapest and most diversely used for medical imaging diagnostics. The goal of the ongoing development on one hand is to produce clearer US images with higher resolution (finer details), and on the other hand to decrease the size of the US devices to improve portability. One of the most important breakthroughs in medical US imaging was the advent of the color Doppler US method, which is a non-invasive technique to directly measure the blood flow within the heart or in any other organ that the US wave can reach [6].

Since there are no known harmful side effects (e.g., ionizing radiation) of the diagnostic US (except for some specific cases, like the local heating in a certain wave range), it is routinely employed in numerous clinical procedures, named ultrasound-guided interventions. For example, during a breast biopsy, US can be used as a real-time needle tracker tool to guide the physician to the target anatomical structure along the planned trajectory. Efficient software algorithms are also able to support interventional radiology with automated segmentation [7]. Novel "ultrasound-on-a-chip" and similar manufacturing techniques promise further improvements, such as integration with robot-assisted minimally invasive surgery and more creative utilization in the near future [8, 9].

Since the proper evaluation of a US image requires years of practice, it is important to train the sonographers in a practical and lifelike environment. There are several studies giving recommendations about the number of examination to be performed during their training period:

- 20 mentored examinations are recommended for sentinel node biopsy [10];
- 25 for fetal echocardiography [11];
- 300 for critical care [12];
- 480 for echocardiography [13];

- the European Association of Cardiovascular Imaging (ESC) also recommends hundreds.

Unfortunately, these high numbers may still not be enough to develop the proper US-based diagnostic skills. In an earlier publication, it was shown that after the recommended number of cases on the physical simulator, some physicians had problems performing real-life examinations (effect of over-training) [14]. It can be concluded that the education of medical US is a major challenge, and computer-driven US trainers could provide the expected enhancement. Studies showed that physicians who received not just theoretical, but simulator-based training as well, cloud significantly improve their skills in the evaluation of US images [15]. Another study involving 262 clinical fellows showed that performance depends on the number of years spent as a resident, and on the number of scans performed during these years. However, the number of didactic hours spent on US did not lead to measurable improvement in the residents' performance beyond 15 hours per year [16].

Simulated US training devices (relying on sophisticated human phantoms or completely simulated tool–tissue interaction) have become a financially and practically appealing solution for many medical educational institutions [17]. Systematic skill measurement (i.e., measuring the learning curve [18]) and credentialing (offering certificates for skill training) are also key advantages present. In 2013, the Consortium for the Accreditation of Sonographic Education endorsed a new US simulator based training program to help standardizing assessments and educations [19].

During the last few years, numerous experimental US trainer projects have been launched with the aim to develop commercial devices, primarily for teaching schools.

This paper provides a survey of the State-of-the-Art US training solutions. In the Section 2, the latest available training practices are introduced, then the main simulator development directions and categories are reviewed in Section 3 and last, in Section 4, a technological overview is provided.

2 A review of computer-driven training approaches

US training has a long tradition. Widely recognized organizations, like the Society and College of Radiographers, the Radiological Society of North America and The British Medical Ultrasound Society [20], are committed to education, development and standardization of US procedures. They published a handbook "Guidelines for Professional Ultrasound Practice" recently[1], as the most important source of information for both experienced sonographers and other medical practitioners. This book provides a general and organ-specific overview of US examinations. The first part contains information about the safety of the medical US, ergonomic practice, including patients with high Body Mass Index (BMI), examination times, and last but not least contains guidelines on how the sonographer should perform the intimate examinations professionally.

[1] https://www.bmus.org/policies-statements-guidelines/professional-guidance/guidelines-for-professional-ultrasound-practice

The need for high throughput education and training became clear for US, but until 1995, no international, and very few relevant national recommendations were published. In 1995, the World Health Organization (WHO) published the first training manual in this topic [21]. The rapid development of US equipment and indications for the extension of this medical imaging procedure into therapy indicated the need for a new ultrasonography manual. In 2011, the WHO published a new manual for medical US [21], which presents the requirements towards the practitioners', and describes important guidelines ranging from the basic physics of US to the detailed description of each organ's or body part's examination. It starts with general rules and recommendations, the list of general indications for B-Scan and duplex techniques, patient positioning, coupling agents and the interpretation of the US images of different body parts, the choice of the proper transducer, the preparations and the scanning technique described. The normal and the pathological findings are also discussed accompanied by rich visual illustration [21].

These manuals demonstrate what shall be the baseline knowledge for medical practitioners. Based on the clinical experience and practical competencies, a multi-level concept of US practice would be feasible. The European Federation of Societies for Ultrasound and Biology proposed the following minimal training requirements divided into 3 levels [22]:

- Level 1 practitioners are required to perform common examinations safely and accurately, they also have to recognize and differentiate normal anatomy, common abnormalities and pathologies;
- Level 2 extends Level 1 requirements with recognizing and diagnosing almost all pathologies, performing basic, non-complex US-guided invasive procedures;
- Level 3 is the most advanced level of practicing, where performing special US examinations and advanced US-guided invasive procedures is required.

US scanning protocols in emergency (ER) care also belong to the critical part of the training, since in trauma care (e.g., patients in shock, respiratory distress, and cardiac arrest), typically US can provide the fastest, yet reliable diagnostic support [23]. The major emergency US protocols include the followings: ACES, BEAT, BLEEP, Boyd Echo, EGLS, Elmer/Noble, FALLS, FAST, Extended-FAST (eFAST), FATE, FEEL-Resuscitation, FEER, FREE, POCUS, RUSH-HIMAP, RUSH, Trinity and UHP, covered by large international professional organizations [24–26].

One of the main problems for novice practitioners is the mental mapping from 2D US slices to 3D anatomy [27]. Computer-based simulators have an important role, here with the main advantage of the wide range of available cases, which are stored in a "case database". Manufacturers create their own databases, which consist of many simulation scenarios grouped to modules by the simulated organ or body part. With these, typical, yet very important US procedures can also be simulated [28–31]. Using US simulators together with case databases, a highly standardized educational program can be developed, and objective requirements can be set for assessment. Another major advantage of these simulators is the ability to show a virtual 3D model of the examined anatomic region. These 3D models help to build the *mental model* of the anatomy, which is one of the core skills the sonographer must acquire. The virtual feedback allows to verify the mental model, mapping the 2D ultrasound plane to 3D anatomic structures and vice versa [32]. There are fundamental US examinations, like echocardiography, where it is challenging to identify the critical parts of the heart [33], because there is very little contextual information. In other cases, like intravascular US examination, there is a completely different workflow to be employed [32].

A virtual model can visualize anatomic parts in 3D, which opens up numerous training concept variations to the practitioners. A virtual scene allows to decrease the level of complexity by hiding the irrelevant organs, and showing the more important information in greater details. Most simulators show not just the scan plane, but importantly, the surface of the virtual patient, bones, skin, etc. as well.

In the past few years, Augmented Reality (AR) applications emerged in the medical field, and this domain is also contributing to an unprecedented boost in medical education technology. In [34], two methods were compared, how AR can be used for US training. Many modern computer-based US simulators aim to resolve this by showing a 3D model of the examined anatomy, but these are still rendered on a 2D screen. At the high end, e.g., EchoPixel's True 3D Viewer allows to visualize and interact with tissues and organs in a completely open 3D space [35].

3 Methods for Simulated Ultrasound

Since computer-based simulators do not use real US probes and realistic phantom models, the output image shown during the training falls behind reality. A high fidelity and fast method is required to synthesize the simulated US slices, depending on the position and orientation of the dummy probes. In the literature, three major methods can be found to generate US-like images [32], and the following subsections give a brief explanation of the different approaches:

- interpolative;
- generative image-based and
- generative model-based method.

3.1 Interpolative method

The interpolative simulation of US is the most widely employed method to produce synthetic US output. In this case, the 2D images are interpolated from pre-acquired, rendered 3D US volumes. The quality of these interpolated images can be very high, since they are derived from real US source. At the same time, the quality of the results depends on the probe's orientation, because US images have view-dependent qualities. Accordingly, in the off-line pre-process phase, undesirable artifacts should be removed, and during the on-line simulation, the simulated image should be enhanced to include the proper view dependent features [36]. If the acquired 3D ultrasound volume contains artifacts, it is difficult to replace them with correct data. A viable workaround could be to acquire several volumes from different viewpoints, yet a high number of volumes is required. The US simulators employing this technique may require an algorithmic solution to collect 3D volumes from real patients that can be managed by free hand scanning [32]. During the acquisition, the transducer puts pressure on the skin, resulting in tissue deformation, but there are efficient algorithms and models to correct these [37]. Compared to other methods, the major advantage is the simplicity of the implementation, leading to a real-time realization [32].

3.2 Generative image-based method

Generative image-based methods synthesize US images from other modalities, like Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). These are typically aimed for for non real-time applications (e.g., transducer design) to simulate wave propagation. To enable the use these methods in real-time applications, the synthesis of US-like slices from other types of images needs to be optimized; broken down into pre-processing and run-time phases. Shams et al. presented a novel method in which the pre-processing phase produces detailed fix-view 3D scattering images, and the run-time phase generates view-dependent US artifacts [38]. An acoustic model was also developed of the US in the run-time phase. Combining the scattering images with the generated ones by the acoustic model results in real-time US images. In [39], a CT-based tissue model for US simulation was presented, which relies on an estimation of the transfer function from a 2D CT slice into a tissue model applicable to US simulation. This approach also requires an offline preprocessing phase to produce the necessary inputs for the simulation algorithm, such as the acoustic map, back-scattering map and the attenuation coefficient map. In the case of CT, the correlation between the Hounsfield units and acoustic impedance was derived in [36, 38], and used to simulate absorption, reflection and transmission. The main advantage of this CT-based method is that large patient datasets are already available.

3.3 Generative model-based method

To simulate small and moving anatomies, such as the heart, the generative methods based on CT do not provide information at the expected level of details. To overcome this problem, computer modeling the anatomy is one solution. In the literature, numerous heart models can be found, however most of them are static. The dynamics of the heart cannot be handled realistically with static geometric models, thus in [40], a time-varying mathematical model was presented for vessel-representations of the human heart, and in [41], time-varying MR volumes were used to construct a heart model. One major drawback of model-based simulation is a very complicated procedure to generate new cases. Ontologies can also be used to construct high-fidelity heart models for US simulation, however, those cannot be generalized easily [40].

4 Available products and technologies

In this Section, commercial US simulators are surveyed to highlight the most important characteristic of the training products currently available. In order to give a comparative review, discussion is based on the following common set of criteria:

- the basic features provided;
- US simulation method employed;
- training concept *(where known)*;
- supported US scanning protocols;
- user interface and interaction;
- clinical validation/development status;
- DICOM compatibility.

Table 1 presents a comprehensive overview of the commercially available systems to the authors' best knowledge. Beside these rather concrete aspects, the user interface is also critical, thus the properties and issues related to the user experience are addressed. The user interface necessarily consists of an input and output device; in this context, input devices are the different kind of dummy transducers, and the output devices are mainly visual displays. Probe tracking is an integral feature of the simulators, and thus each system incorporates orientation and position sensors, but tracking technology and methods vary [42]. For example, the CAE Vimedix and Schallware simulators use an expensive electromagnetic system to record the probe pose relative to the mannequin, while the SonoSim simulator's probe is based on a more affordable RFID positioning technology to acquire location information [43].

In the following subsections, the most popular systems are reviewed based on the above mentioned criteria.

4.1 Vimedix

Vimedix is a recent US education platform (developed by CAE Healthcare, Montreal, QC) (Fig. 1). It contains 3 base modules running on a common software platform: Vimedix Cardiac, Vimedix Abdo and Vimedix Obstetrics / Gynaecology (Ob/Gyn). The Cardiac and Abdo modules support the TTE and TEE, furthermore they also support Color Doppler, Continuous Wave Doppler and Wave Doppler of the Heart simulations. These modules, particularly the TTE and the TEE, require a detailed, anatomically correct solid beating model of the heart. To serve these requirements, a model-based generative simulation was necessary, that can also replicate artifacts and give an opportunity to find the appropriate acoustic windows [28, 32, 44].

It provides male and female multi-purpose mannequins, a phased array, transq-esophageal and curvilinear transducers (Fig. 1). With these devices, most of the real-life and frequent US examinations can be simulated. The Vimedix training software's

Table 1
Summary of the commercial ultrasound simulator systems

Simulator	Simulation methods	Training material	Basic feature set
Vimedix	Generative model-based simulation	Cardiac, Abdo, Ob/Gyn, E-Learning	Doppler, 3D AR, Bi-Plane and M-Mode
SonoSim	Generative image-based method (Pre-recorded 3D US by free hand)	Modular format: course, knowledge assessment, hands-on training with numerous cases	virtual human patient, Power Doppler, Real-Time Assessment and Performance Tracking
Schallware	Generative image-based method (By free hand)	Internal medicine, ER, Ob/Gyn, fetal heart cases	B Mode, M Mode, 4D B Mode, Colour Doppler, ROI
UltraSim, Compact-Sim	Interpolative method (Pre-recorded 3D US)	Abdomen, Ob/Gyn, Breast, Vascular, Neck and ER	B-mode, Color and Spectral Doppler, Intuitive control panel
ScanTrainer	Interpolative method (Pre-recorded 3D US)	Transvaginal, Trans-abdominal, Ob/Gyn, FAST, eFAST	B Mode, M Mode, Doppler, haptic probes, virtual patients

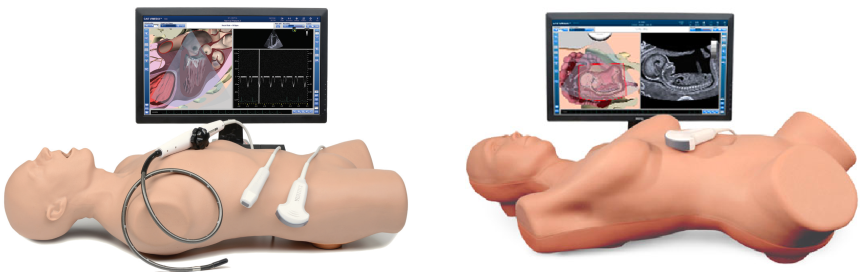


Figure 1
The Vimedix Cardiac, Abdo (left) and the Vimedix Ob/Gyn platforms [28].

Cardiac/Abdo module has over 150 pathological cases validated through numerous scientific publications, and the Ob/Gyn module has over 40 pathologies from the first and second trimester of pregnancy.

Both modules support 3D augmented reality with animated anatomy that can be moved and rotated in 3D to learn structure identification and spatial orientation. The Vimedix displays this animated model side-by-side with the simulated US images to enhance the efficiency of the training (Fig. 2).

Vimedix also provides measurement functionalities, including length, diameter, circumference and area of structures. Report functionality is also supported, which is consistent with typical scanning protocols and workflows. DICOM compatibility may also be an important feature, yet there is no public information about it.

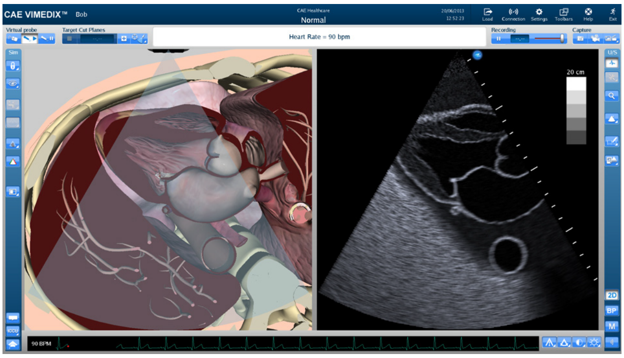


Figure 2
The Vimedix simulation software. The 3D animated anatomy (left) is matched with the simulated US image(right) [45].

CAE Healthcare developed an online training solution and an interactive learning management system called ICCU E-Learning, which contains more than 30 hours of multimedia and interactive content. Since it is an online solution, it is accessible from any platform, including mobile devices [46].

4.2 SonoSim Ultrasound Training Solution

The SonoSim Ultrasound Training Solution (SonoSim Inc., Santa Monica, CA) provides an integrated hands-on US training, didactic instruction and assessment. This laptop-based solution can be used without complex and expensive mannequins that makes it altogether light and portable (Fig. 3).

Since basically this is a mannequin-free simulation platform, a photorealistic 3D virtual human body model is used to represents the anatomical structures. The orientation of the US probe is mapped onto this virtual human body, and the virtual US beam is showed based on the probe's pose in real-time. This feature is extended with an optimal US window acquisition guidance, which helps the practitioner to choose the appropriate US window for each anatomic structure. SonoSim uses a freehand method and a special acquisition system to collect US volumes from real human patients. These are stored and post processed to build the case database, which can be used by the simulator to show US images [47].

The content of the US training modules is organized as follows:

- Advanced Clinical Module;
- Anatomy and Physiology Modules;
- Core Clinical Modules;
- Procedure Modules.

Figure 3
SonoSim's solution can be used without a mannequin, as it provides a virtual patient instead [48].

All of these have numerous submodules, which contain well-defined simulation cases, like Ob/Gyn, Focused Assessment with Sonography in Trauma (FAST) cases, etc., starting with an overview of the role of the given case, then describing the affected anatomic structures, the optimal transducer selection, further demonstrating the appropriate patient positions and the imaging techniques. SonoSim has another solution, called LiveScan, which allows to involve both live volunteers and mannequins into US training. In this setup, RFID tags are used to designate the anatomic locations on the human volunteers or on the mannequins (Fig. 4). The SonoSim LifeScan solution provides important additional cases like Critical Care (RUSH), eFAST, Cardiac Resuscitation Cases, etc. The training of these cases was shown to be efficient with mannequins and human volunteers [49]. With the SonoSim Case-Builder, customized US training cases can also be created [31, 50].

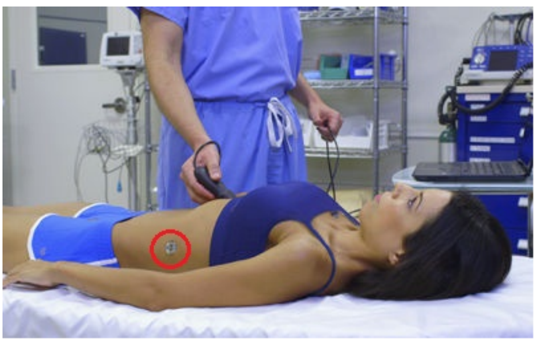


Figure 4
The SonoSim LifeScan solution may involve human volunteers for higher fidelity. RFID tags (circle red) are used to designate the key anatomic locations [49].

The SonoSim simulator shows the simulated US image and the related virtual anatomic structure on a split screen (Fig. 3). This kind of data representation is efficient to develop the sonographer's mental mapping between the 2D US image and the 3D anatomy. SonoSim provides one US probe to simulate all the cases from its database. Compared to the Vimedix, this makes the SonoSim's simulator more portable and affordable. There is no information available about the clinical validation of SonoSim, but based on the testimonials, this simulator is popular and widely used in clinical education. Information about DICOM compatibility is not provided, however the real-life patient volumetric US data is stored in DICOM format [51].

4.3 Schallware ultrasound simulator

The Schallware US simulator (Schallware GmbH, Berlin, Germany) provides mannequin-based US simulation for general practice, emergency cardiology and gynecology (Fig. 5). These modules are produced at the company's internationally recognized affiliate clinics with a special Schallware US free hand acquisition system, and distributed with a tutorial including documented patient cases. During the acquisition process, they used up to 2000 raw B-scans to construct one 3D volume, in order to gain optimal resolution. This pathology database contains more than 400 cases from real patients, including a medical history, questions leading to a diagnosis and comments on US findings. The major scanning protocols like TTE, TEE, FAST, eFAST, Focused Echocardiography in Emergency Life support (FEEL), etc. are also included in the repertoire. The simulator supports all the major US visualization types, such as B Mode, M Mode, Colour Doppler and 4D Colour Doppler. Some cases with accompanied MRI and CT images are also available (Fig. 6).

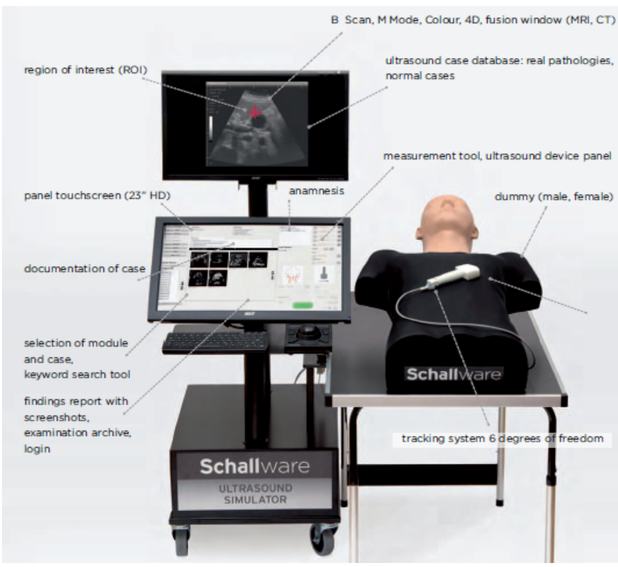


Figure 5
The mannequin-based Schallware US simulator [30].

The Schallware simulator was designed with two displays (Fig. 5), the top screen displays the US image, while the bottom touch screen exhibits the related information, like the documentation of the case, the anamnesis, the measurement tools, the module selector and the reporting functions. The dummy probe repertoire satisfies the most common clinical demands (Fig. 7).

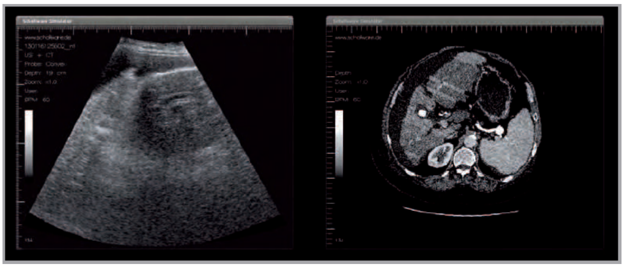


Figure 6
CT/MRI synchronized to US data employed with Schellware US simulators [30].

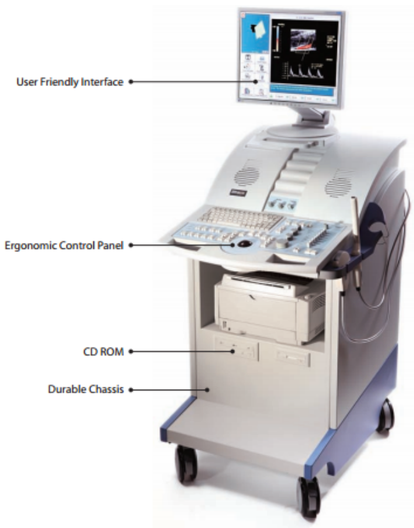
Figure 7
The Schallware's dummy probe repertoire (convex, linear, sector, transvaginal probe and TEE endoscope) satisfies the most common training needs [30].

4.4 UltraSim and CompactSim

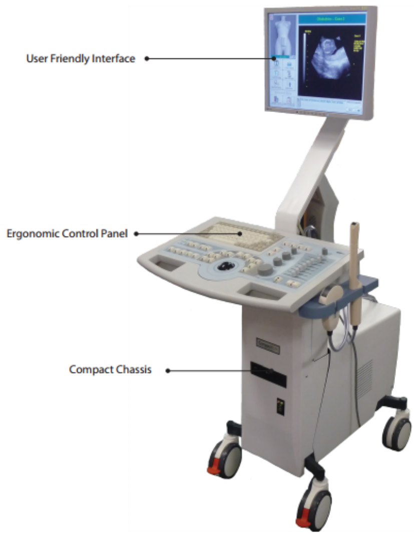
UltraSim and CompactSim (MedSim Inc., Ft. Lauderdale, FL) are mannequin-based US simulators (Fig. 8). These provide a wide range of training modules, the major case repertoire covers abdominal, Ob/Gyn, transvaginal Ob/Gyn, breast, vascular, neck and ER medicine with FAST scanning protocol. The modules built from US volumes acquired from real patients, and consist of two case classifications: curriculum and practice. Each case is organized around a task list used to perform the examination, which are based on standard echocardiography guidelines and internal anatomical landmarks. The curriculum offers complete task lists, lesson plans containing a proper introduction, learning objectives, demonstration lesson, teaching tips and a didactic content outline. These modules allow to directly measure and monitor the practitioners' skills and progress by performing automatic skill assessment. The major imaging features are the B-mode, Color and Spectral Doppler modes [52].

Compared to the previously described simulators, it has a traditional scanning station with a generic control panel. This unique setup with an intuitive control panel allows to practice US knobology. The main US imaging functions (e.g., preset, depth, focus, Time Gain Compensation, frequency, freeze, etc.) are configurable from the control panel with mechanical knobs, like in the case of real devices.

The MedSim provides 3 dummy US probes: the 3.5 MHz is used for abdominal, Ob/Gyn and ER examinations, the 7.5 MHz linear probe is used for breast, neck and Color Doppler studies of the carotid vessels and the 5.0 MHz transvaginal probe is used for Ob/Gyn examinations.



(a)
The UltraSim simulator scanning station [52].



(b)
The CompactSim simulator scanning station.

Figure 8
With their traditional design and realistic control panel, the UltraSim systems provide unique appearance among the commercial simulators [52].

4.5 ScanTrainer

The ScanTrainer (MedaPhor Ltd., Cardiff, UK) provides two mannequin-free platforms for US training: a transvaginal and a transabdominal simulator. The first one allows to perform Ob/Gyn and ER, the second allows general examinations. ScanTrainer uses a curriculum-based training concept with real patient scans, and provides a comprehensive metric-based assessment. The MedaPhor's subscription-based cloud service offers two unique features: the ScanTrainer Case Generator service allows tutors and specialists to upload and publish their own patient scan and self-created cases and the ScanTrainer Case Library offers a cloud-based, continuously growing library with more than 500 normal and abnormal cases. ScanTrainer provides two separate simulation devices (Fig. 9): the transvaginal simulator uses an endo-cavity haptic probe, and the transabdominal simulator uses a special floor-mounted haptic device. These replace the need for a mannequin, and provide a realistic scanning experience. The simulator platform uses two displays: one for the US image and the settings panel and another for the virtual human patient (Fig. 10). ScanTrainer offers a large variety of configuration options, like depth, focus, time gain compensation, measurement and reporting features [53].

Figure 9
The ScanTrainer US training system with the transvaginal (tabletop) and the transabdominal simulator modules [53].

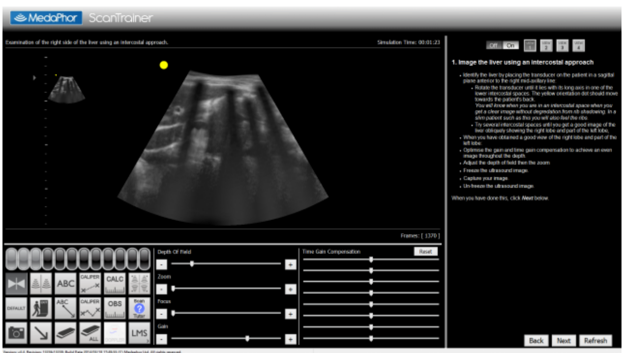


Figure 10
The ScanTrainer's main screen with the US image and the control panel. Features like zoom, time gain compensation, depth, measurement tools are also displayed on this screen [53].

4.6 Portable alternatives

As mentioned in the first section, US devices developed in the last years are getting smaller, giving place to hand-held, portable US devices that still produce clinical quality US images. These are less expensive than the traditional US stations, thus they are more affordable for educational purposes as. Clarius Inc. (Burnaby, BC) is a U.S.A. Food and Drug Administration (FDA) approved hand-held wireless device with linear and convex transducers [54] (Fig. 11). These are designed for clinicians to perform daily bedside US examination. To display the images provided by Clarius, a mobile application (with Android and IOS support) is required to connect via wireless. Its high resolution US images, the DICOM compatibility, the automated gain and frequency setting and the waterproof magnesium shell make this device competitive on the market [55].

Figure 11
The Clarius hand-held wireless US scanner. The convex probe used to examine organs with depth of 3–30 cm, and the linear type used to examine organs with depth of 1–7 cm, while the Endocavity is mostly for Ob/Gyn [55].

Another practical US tool is coming from TELEMED (Fig. 12), in the form of a computer-based US system. It supports numerous imaging modes such as B-Mode, M-Mode, Color and Power Doppler. Their broad range of transducers repertoire allows to perform the most common important examinations. It requires a laptop and a software provided by TELEMED to display the output images [56].

More recently, various (Asian) developers appeared with even smaller and lighter US tools, however, their certification (CE or FDA) is still pending, thus they are omitted from this review. Nevertheless, it is clear that cheaper alternatives can be provided for US training, relying only on a mobile phone or other smart devices.

A new concept appeared on the market, the iNNOGING (iNNOGING Medical Ltd., Israel), which employs the model-based generative method for remote evaluation and diagnosis of US [57]. Particularly, their software converts data from any US device into a 3D representation of the scanned area, that then can be manipulated, analyzed and evaluated using a same transducer, offering dynamic, real-time examination of the pre-recorded data set. Arguably, this technology could well be used in training as well.

Conclusion

Since medical ultrasound is a generally employed, non-invasive and relatively cheap imaging modality, it is important to train practitioners how they can use them properly and effectively. It is also critical to teach to evaluate the images produced. During the MD education, US simulators can be used to practice from the basic to expert examination techniques. There are many great US simulators available on the

Figure 12
The TELEMED's computer-based US system [56].

market, relying on advanced computer modeling. Some simulators are mannequin-based (linked to a physical examination phantom), while others replace the mannequins with virtual patient displayed to the practitioner. Another differentiating property of these is the simulation method they rely on. *Interpolative methods* use pre-acquired US volumes to produce the simulated 2D US image, while the *generative image-based methods* synthesize US-like images from CT or MRI, and the *generative model-based methods* use precise mathematical models to simulate the US images of different organs. These are mainly used in the case of moving anatomies, such as the heart. As an alternative solution, the recently emerged hand-held US scanners could be taken into consideration as a direct competition to the traditional simulators. These are less costly, while they can already provide clinical-grade image quality. Since US simulators have been clearly shown to help the practitioners to gain practical experience, their use greatly reduces the risk associated with US-based procedures, and can improve the clinical outcome. In the near future, with the further spread of computer-based methods, the standardization of these training devices and adjacent curricula is expected.

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