Imaging and Image Transfer in Emergency Medicine

Guest Editors: Tobias Lindner, Hein Lamprecht, Efthyvolos Kyriakou, Raoul Breitkreutz, Stefan Puig, and Aristomenis K. Exadaktylos
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Editorial

Imaging and Image Transfer in Emergency Medicine

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This special issue presents an international forum for researchers to summarise the most recent developments and ideas in the field of emergency imaging and image transfer, with a special emphasis on the technical and observational results obtained within the last five years.

First of all, we would like to thank all the authors for their contributions. For reasons of space, we were forced to reject other submitted papers. Secondly, we are very much obliged to our reviewers for their excellent and punctual work.

It is a basic duty of emergency medicine to rule out severe illness or to recognise it and treat it at once. Like point-of-care biomarkers, bedside imaging techniques may play a substantial role in coping with this task. In times of increasing pressure on emergency physicians to deliver faster and better results, rational use of imaging techniques during the very first minutes and hours from the time of admission is of the greatest interest. This not only improves outcome and decreases morbidity and mortality but also saves money and enhances patient satisfaction. C. A. Pförtmueller et al. address the issue of quality management on emergency wards. By comparing six different methods of assessing patient satisfaction, they concluded that patient-optimized online assessment performed in the hospital can give a very good response rate. Pförtmueller et al. recommend involving an external institute, as this can save time and money.

Ultrasound (US) is a 24/7 bedside and also prehospital point-of-care imaging tool and was the theme of several studies submitted to this special issue. M. J. El Sayed and E. Zaghrini review current and future indications of preclinical US. They point out that US can help prehospital providers to guide management in several settings (e.g., trauma, cardiopulmonary resuscitation). Despite the great prehospital potential for US, they see problems in developing an adequate training concept for nonphysicians, in order to ensure that they gain and maintain sufficient skills. Moreover, further outcome research is needed to show the benefits of preclinical US. R. Breitkreutz et al. tested the influence of the integration of personalised US on in-hospital patient management. They conducted four substudies on image quality, work distribution, and diagnostic and procedural quality of US in critical care medicine. They found out that integration of personalised US during their regular ward rounds significantly reduced average contact time per patient and lowered the patient referral rate to an echo lab from 20% to 2%.

In a retrospective study enrolling almost 20,000 patients in a level 1 trauma centre, A. Y. Sheng et al. show that the introduction in recent decades of focused assessment with sonography in trauma (FAST) has led to an equivalent reduction in the annual rate of abdominal computed...
tomography (CT) (around 2%), whereas the overall use of CT in emergency departments has risen during this period. The authors conclude that FAST can avoid unnecessary radiation exposure and also reduce costs in a relevant number of trauma patients. Their future aim is to establish a safe “FAST-only” algorithm. In another ultrasound study, K. Layman and colleagues focus on the use of US in the ED in the evaluation of pain or bleeding in the first trimester of pregnancy. On the basis of three typical cases, they review common pitfalls and discuss key principles of US use in this setting.

Four further papers on ultrasound deal with teaching concepts and protocols for the clinical use of ultrasound, even by inexperienced examiners. T. V. Mai et al. investigate the feasibility of a brief cardiac limited US examination protocol (CLUE) performed by three trainees who have no prior US experience at all and who use a pocket-sized ultrasound device (PUD) under wireless audiovisual guidance from an off-site cardiologist. Data were transmitted through the camera of a phone attached to the PUD. The technical quality of the images and diagnostic accuracy (LV systolic dysfunction, LA enlargement, ultrasound lung comets, and elevated CVP) were compared to clinical routine (on-site echo threshold). Referring to their results, authors conclude that, under these circumstances, a novice can perform the CLUE protocol and facilitate off-site/bedside medical decision making. M. Campo dell’Orto et al. describe a self-made phantom training model using a celluloid table tennis ball for ultrasound-guided pericardiocentesis. On the basis of its evaluation by 67 participants in the course of a focused echocardiography training session, they conclude that their phantom is an effective training tool for acute and critical care physicians. C. Cuca et al. (a member of the same group) evaluated a self-developed interactive online training program for the ultrasound of the thorax, trachea, and lung by comparing the success of independent theoretical skill development through their individual e-learning course compared to a day-long training seminar with personal attendance. They found that e-learning almost equalled scores of classroom-based training with respect to the gain and retention of factual knowledge. They therefore considered that this was set to become a vital part of theoretical training in lung ultrasound. The third paper on training concepts for ultrasound skills from R. Breitkreutz et al’s very active research group describes the development and assessment of a structured clinical examination curriculum for focused thorax, trachea, and lung (THOLUUSE) ultrasound in emergency and critical care medicine. In a prospective educational study, medical students, anaesthesiologists, and trauma surgeons underwent a one-day training course structured according to their concept. Training included lectures in physiology, the sonoanatomy and sonopathology of the thorax, case presentations, and hands-on training, including ultrasound phantoms, puncture models, and healthy models and selected patients. They concluded that their course significantly improves theoretical and practical skills for the diagnosis of acute thoracic lesions, including pleural effusion/haemothorax and pneumothorax.

Another section of this special issue is dedicated to recent technical developments and their potential benefit in medical care. M. Tabbara et al. introduce the Swiss Limmex Emergency Wristwatch, as launched in 2011. By pushing a button on this watch, the wearer can initiate multiple emergency calls and establish mobile communication with a preselected person, institution, or a search and rescue service. Due to the rising number of elderly people who want to live on their own in their private homes, technical developments like this are of increasing importance. Such devices can assure safe storage and automated or easy transmission of relevant personal medical data, supporting fast and reliable medical treatment in an emergency. In their study, the authors present the results of a survey with 620 answers (response rate 46%) of watch wearers with a mean age of 81.8 years. G. Lindner and A. K. Exadaktylos review previous clinical studies on the accuracy of noninvasive haemoglobin measurements using pulse carboxyoximetry devices and discuss their potential usefulness in different clinical settings, and also in prehospital triage. T. Lindner et al. present the clinical results of the recently introduced PneumoScan, a noninvasive bedside device that uses micropower radar technology to detect pneumothorax. The authors consider that this device might be used in the prehospital setting and for triage in disaster medicine, as the scanner is not examiner dependent like ultrasound and is easy to use only after a short tutorial. However further clinical evaluation is necessary. A. K. Zisakis et al. describe several new and interesting devices that are still in the early phase of clinical testing but one day could help in diagnosing brain injury, measuring intracranial pressure, or even reopening occluded brain vessels. These devices are not exclusive for neurosurgeons or neurologists but also for nonspecialists.

S. P. Whiley et al. present the new Johannesburg trauma protocol which implements the Lodox Statscan, a low dose, full-body X-ray scanner. Its use as a triage tool is illustrated by the description of 63 patients scanned on entry to the ED in a single shift at a level 1 trauma centre. The authors draw the conclusion that this method of imaging can be an efficient and accurate method of triage in underresourced situations. U. J. Gupp et al. ask if the radiation dose to severely injured patients in emergency CT scans can be reduced whilst maintaining image quality. They therefore examined the impact of adaptive statistical iterative reconstruction (ASIR) on CT imaging quality, diagnostic interpretability, and radiation dose reduction for a proven CT acquisition protocol for total body trauma. They compared 30% and 40% of iterative reconstruction (IR) modification in the raw data domain of the routine total body protocol with the routine protocol itself. The authors presented only small numbers of patients in preliminary results and regarded their study as a feasibility evaluation of IR algorithms in an emergency setting. They cautiously concluded that the use of IR algorithms is a promising approach to reduce radiation exposure without compromising radiological interpretability, even in an emergency setting where image quality is paramount.

Finally, K. N. O’Laughlin et al. address the topic of risk stratification for brain herniation after lumbar puncture (LP). Firstly, they asked members of an expert panel to define which head CT findings indicate an increased risk of herniation following LP. Secondly, they used clinical data of a
cohort of patients who had a head CT for any reason to assess the ability of history and physical examination to predict those findings. They concluded that no patient history and no findings during clinical examination alone or in combination are adequately sensitive to detect head CT abnormalities believed to predict enhanced potential for brain herniation during LP.

Acknowledgment

Once again, we would like to thank the authors, their coworkers and our reviewers for contributing to this special issue and hope the reader will find a lot of interesting and stimulating contents for his daily life in the medical service.

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Raoul Breitkreutz
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Research Article

Does the Integration of Personalized Ultrasound Change Patient Management in Critical Care Medicine? Observational Trials

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Objective. To test the influence of personalized ultrasound (PersUS) on patient management in critical care. Design of the Study. Prospective, observational, and critical care setting. Four substudies compared PersUS and mobile ultrasound, work distribution, and diagnostic and procedural quality. Patients and Interventions. 640 patient ultrasound exams including 548 focused diagnostic exams and 92 interventional procedures. Main Outcome Measures. Number of studies, physician’s judgement of feasibility, time of usage per patient, and referrals to echo lab. Results. Randomized availability of PersUS increased its application in ICU work shifts more than twofold from 33 to 68 exams mainly for detection and therapy of effusions. Diagnostic and procedural quality was rated as excellent/very good in PersUS-guided puncture in 95% of cases. Integrating PersUS within an initial physical examination of 48 randomized cases in an emergency department, PersUS extended the examination time by 100 seconds. Interestingly, PersUS integration into 53 randomized regular ward rounds of 1007 patients significantly reduced average contact time per patient by 103 seconds from 8.9 to 7.2 minutes. Moreover, it lowered the patient referral rate to an echo lab from 20% to 2% within the study population. Conclusions. We propose the development of novel ultrasound-based clinical pathways by integration of PersUS.

1. Introduction

Point-of-care ultrasound has become more popular in the environment of acute and critical care medicine [1, 2]. Various recommendations on its use mainly address clinical indications related to acute or severe dyspnoea, hypotension and shock, trauma, and abdominal pain [1–4]. The technical concept of a “personal ultrasound imager” and an “ultrasonic stethoscope” is more than 30 years old [5]. There is a strong interest in the integration of ultrasound into clinical pathways and many context-based protocols are available. A novel technology was born when the initial idea of a personalized ultrasound device (PersUS) used like a physician’s generic stethoscope was realized [5, 6], a paradigm shift that now supports real point-of-care clinical pathway concepts. In 1978 it was suggested that bringing the echo lab to the patient would be a major step forward [5]. Previously, ultrasound labs contained stationary ultrasound systems, while mobile and hand-carried ultrasound was kept at facilities like emergency departments or intensive care units, making the technology
available for multiple users. In fact, “personalized” refers to the size and quick application of the PersUS, like a mobile phone or stethoscope, allowing greater flexibility in its usage. There is an ongoing debate as to whether miniaturization of ultrasound machines can improve patient care. The potential personalized usage opens up the field of ultrasound in acute and critical care medicine for a large group of new users [3]. However, only rarely have concepts or strategies for clinical integrations been tested for the critical care environment and little has been established in the way of clinical integration and workflow [7]. Our aim, therefore, was the analysis of the feasibility of clinical integration, frequency of use, decision making, and time consumption of PersUS implementation in the daily routine.

2. Methods

2.1. Study Design. Ethical approval was obtained from the Institutional Ethics Committee for Human Studies, University Hospital, Frankfurt am Main, Germany (application number 2/II, 13.1.2011). A prospective observational study with data-controlled acquisition was performed.

2.2. Study Setting and Substudies 1–4. Patients were enrolled between July 2010 and September 2011. Personalized ultrasound (PersUS) was performed in four centres of the authors and in each case using the Vsca gnete (GE Healthcare, Wauwatosa, WI, USA). After an opening and booting time of 25 seconds, the device allows ultrasound exams with a phased array sector probe (1.7–3.8Mhz) in B-Mode with harmonic imaging and color-coded flow mapping (color Doppler) on a 3.5-inch screen. Support was provided through the “Vscan gateway” (GE Healthcare, Wauwatosa, WI, USA) for all participating examiners. Physicians were trained in focused ultrasound exams in critical care medicine for general applications of the thorax and abdomen and documented each exam with a notation on the patient chart and/or images or clips for later review within the study protocols. Two investigators were staff attending cardiologists and three investigators were staff attending anaesthesiologists or intensivists. Junior staff with expert knowledge in emergency ultrasound performed substudies 3 and 4. Images or clips were deleted after review by the respective attending or study control centre to ensure anonymity. Alternatively, the study protocol allowed a mobile ultrasound device (MobUS) to be used. By chance this was always a Vivid-i (GE Healthcare, Wauwatosa, WI, USA) with each collaboration partner. To examine a great number of patients with a broad spectrum of diseases, this trial was subdivided into four distinct substudies.

2.2.1. Substudy 1. Our hypothesis was an availability-based increase in the use of PersUS. We tested this hypothesis in two independent intensive care units with two ultrasound-capable physicians (one cardiologist-intensivist and one anesthesiologist-intensivist), respectively. The practitioners had access to the PersUS device—carried on person—on either odd or even days, which was determined randomly.

2.2.2. Substudy 2. Four critical care physicians studied PersUS for planning an execution of ultrasound-guided needle punctures, such as pleural, pericardial, abdominal, or urinary bladder punctures for evacuation of fluid or inserting catheters (pleurocath, pigtail, or suprapubic). Linear analogue self-assessment was used to obtain semi-quantitative data of the physician’s impression of (i) diagnostic quality and (ii) visual support in ultrasound-guided intervention. Any relative value above 90% was graded as “excellent” and between 80 and 90% as “good” or between 70 and 80% as “satisfactory.”

2.2.3. Substudy 3. We measured the mean duration of a physical examination with PersUS integration according to the decision of a single emergency physician who used PersUS after randomisation by coin toss. Our null hypothesis was that PersUS exam integration does not significantly prolong the examination time. Indications were acute dyspnoea, thorax pain, hypotension, or abdominal pain. The time between examinations beginning and end (handshake following exam) was measured by a generic stopwatch. Any influence on patient management due to PersUS was noted. Of note, PersUS was used during the first patient contact and integrated into the examination. All patients needing ultrasound, for example, to exclude pericardial effusion, received the US with the MobUS device as usual.

2.2.4. Substudy 4. In a cardiological and nephrological speciality care unit a PersUS device was randomized between two wards by switching its presence or absence on alternating calendar days. One senior cardiologist alone was informed as the study coordinator of this substudy and allowed to make the PersUS available or remove it from the respective ward. The ward rounds teams, consisting of one or two staff physicians and one attending physician, were blinded to the study aims and differed from day to day. They were instructed to use PersUS whenever it was available and deemed necessary and to note the times and indications of use. Time between beginning and end of ward rounds was measured as well as the number of patients seen and the type and length per ultrasound exam. Most of the examinations during the ward rounds were focused on LV function as well as effusions. More subtle examinations such as diastolic function of valve regurgitations were sent to the echo lab. The quality of the exam was graded on a Likert scale regarding diagnostic quality as judged by the examiner. All data was then sorted into Group A (control group without PersUS) or Group B (examination with PersUS). Exam time per patient per ward round was calculated. Our null hypothesis was that the exam time per patient would not change significantly by using PersUS on ward rounds.

2.3. Study Entry Criteria. Patient inclusion was based on the decision of the participating treating physician. After informed consent, patient-related data and procedure details were logged either on a data acquisition sheet or into a paperless database. If patients were unable to give their informed consent (sedation, dementia) relatives were informed. All
interventions were applied only after a generic routine
MobUS confirmed the initial findings. Indication was for-
mally only supported by MobUS findings and no additional
interventions were performed based on PersUS findings
alone. Participating physicians were briefed on the imple-
mentation of PersUS. Patients below 18 years of age were
excluded from the study. Bias could not be controlled oth-
erwise.

2.4. Data Analysis. Physicians interpreted all ultrasound
exams at the time of the scan and completed the data
acquisition protocols upon exam conclusion. Unless stated
otherwise, continuous data is shown as mean ± standard
deviation. Box plots show median (bold line), mean (dashed
dline), 25th and 75th quartiles, whiskers, and all outliers. The
Mann-Whitney U-test was used for descriptive data analysis
for comparison between the two groups in substudies 1, 3, and
4. Study size was planned with a fixed number of patients.
Power analysis was not applicable for there were no data to
precisely predefine our variables. There were no missing data
to be excluded.

3. Results

Of 31 work shifts (16 without and 15 with PersUS) there were
a total of 101 patient exams with 167 ultrasound indications
(Table 1). Major indications were diagnostic and related to
cardiac anatomy and function as well as pleural effusion
(Table 1).

When only a MobUS was available, 33 patients received
a focused ultrasound exam. In contrast, the availability of the
PersUS markedly increased the number of patients receiving
an ultrasound exam up to 68 (relative change: 106%;
Figure 1(a), Table 1) and allowed interventions such as pleural
puncture to be applied at an earlier point in time. Mean
PersUS operation time per patient was 6.5 ± 3.9 minutes,
1.7 minutes faster than MobUS (Table 1). There was hardly
any difference in cardiac evaluations; however, for thoracic
and other ultrasound examinations there was a remarkable
reduction of hands-on/hands-off time per patient (Table 1).
During a 3-shift intensive care system, PersUS was most
likely to be requested by the physician directly after the
morning ward rounds, followed by afternoon or night shift
ward rounds (Figure 1(b)).

3.2. Substudy 2: Evaluation of Image Quality and Interven-
tional Support. Four attending physicians in critical care
evaluated diagnostic and image quality of the PersUS exam
and its image quality as well as feasibility in interventional
procedures (Figure 2(a)). For pleural effusions, which were
the most common diagnoses within the study, PersUS
was rated “excellent” (Figure 2(a)(B)). PersUS use demon-
strating pericardial effusion and urinary bladder status
(Figure 2(a)((A), (C))) as well as during PersUS-guided pro-
cedural intervention was rated “good,” except in the case of
urinary bladder puncture (Figure 2(a)). Numbers for ascites
punctures (2) were judged similarly. After PersUS-guided
intervention was complete, physician requests for device use
in later punctures increased substantially (Figure 2(b)).

3.3. Substudy 3: Time Requirements of PersUS. Within nine-
teen work shifts in an ED, 48 patients with leading symptoms
acute dyspnoea (n = 21; 44%), abdominal pain (15; 31%),
thorax pain (11; 23%), and hypotension/shock (1; 2%) were
randomized to be examined on admission either without
(Group A; 26 patient admissions, 14 female and 12 male,
aged 59 ± 22 years) or with the assistance of PersUS (Group
B; 22 patient admissions, 9 female and 13 male, 62 ± 21
years). The duration of this “quick check” initial physical
exam in Group A was 59 ± 3 seconds (mean ± SD, 95%
CI of mean; 6.8; Figure 3(a)). Integration of PersUS into
an initial physical exam directly upon patient admission in
the ED allowed the quantification of possible excess time
Figure 1: Increased personalized ultrasound use in critical care medicine (substudy 1). Randomized comparison of personalized versus mobile ultrasound. (a) number of exams per work shift; (b) distribution pattern over three work shifts. These results indicate the increase in request of the frequency for ultrasound exams during ward rounds (8 a.m., 1 p.m., 8 p.m.) or shortly thereafter, which can be better implemented with personalized ultrasound.

Figure 2: Physician assessment of diagnostic quality, ultrasound-guided interventions, and reproducibility when using a personalized ultrasound device (VAS scale; substudy 2). (A): pericardial effusion; (B): pleural effusion; (C): urinary bladder. (a) Each left boxplot shows diagnostic ultrasound, each right boxplot ultrasound-guided punctures. (b) Physician assessment of feasibility in ultrasound-guided interventions with a personalized device (VAS scale): inclination to use PersUS in future examinations (each left boxplot) and inclination to use PersUS for other anatomical regions (each right boxplot).

3.4. Substudy 4: Integration into Critical Care Ward Rounds. PersUS was integrated into 53 regular ward rounds with a total of 1007 patients on two wards. Mean ward round operation time was 142 ± 33 minutes with 18 ± 3 patients per ward.

In 194 of 1007 (19%) patient visits, an ultrasound exam was requested due to one or more indications per patient (Figure 3(b), Table 2). According to the randomization, 133 questions regarding 95 patients in Group A remained unanswered as a result of a strict removal of the PersUS. In Group B, when focused PersUS was available, 134 questions regarding 99 patients could be answered while focused PersUS exams were applied at each respective patient contact. The average PersUS examination time was 3.6 ± 2 minutes per patient and was rated 2.4 ± 0.9 (good to satisfactory). Interestingly, this PersUS integration into the ward rounds management effected a significant reduction of the time needed per patient from a mean of 8.9 minutes to 7.2 minutes (Figure 3(b)). Patient referral to the echo lab for further examination was deemed necessary for 95 of 473 patients.

consumption. Although PersUS was integrated easily into this physical exam, it caused a marked prolongation of the examination time to a mean of 154 ± 6 seconds (95% CI 13.2) in Group B (Figure 3(a)). However, in Group B, a change of management in 6/22 (27%) cases as well as valuable additional information for immediate recognition of underlying disease in 19/22 (86%) patients (10 with dyspnoea/thorax pain; 9 with abdominal pain) was registered by the examiner.
(20.1%) in Group A; however, only 12 of 534 patients (2.2%) in Group B with 16 distinct questions were referred. This was mainly the case in request for Doppler examination of diastolic function, which is not yet available in PersUS.

Based on clinical context, ten categories of focused ultrasound examinations were established. (Table 2).

There were no adverse results or effects during any patient exams or interventions with PersUS or MobUS in all substudies.

4. Discussion

The main findings of our studies were that personalized ultrasound was safe, feasible, of good quality, and easily implementable into routine critical care work. The availability of personalized ultrasound increased the requests for focused ultrasound exams and offered an image quality comparable to high-quality mobile ultrasound, allowing targeted decision-making. While PersUS extended the examination time in emergency admissions it positively influenced patient management, increased information gain about the underlying disease, reduced the contact times per patient in ward rounds, and lowered the request for patient referral to an echo lab.

4.1. Feasibility of Integration into Clinical Operating Processes.

Ultrasound and echocardiography in critical care medicine were considered for widespread use [8] and recommended in a recent guideline as a complement to a physical examination in coronary and intensive care units [3]. It has been shown that ultrasound in the ED or ICU supports the early finding of main diagnoses and has the potential to eliminate other differential diagnoses [9, 10]. However, clinical integration concepts are lacking [3, 5]. PersUS allows a more sophisticated integration into the daily workflow and clinical pathways so that ad hoc procedures can be realized.

However, PersUS offers more options: it can complement [11] or replace a complete physical exam while screening [12] or be interwoven with the physical exam or algorithm-like procedures such as the focused assessment of abdominal sonography (FAST). It can be utilised in triage [13, 14] or integrated into the advanced life support as focused echocardiography (FEEL exam) [15–17]. Furthermore, a PersUS could be incorporated into more complex operating procedures such as work shifts and ward rounds.

The ready availability of PersUS increased the number of requests for focused ultrasound examinations. These were not referred to another operator or echo lab but executed as point-of-care exams in real time or shortly thereafter by the same physician determining the indication. The types of indications were related to cardiac chamber dimensions and function as well as pericardial and pleural effusions and reflect recent recommendations for focused echocardiography in cardiology [18]. In critical care and ventilated patients, effusion diagnostic and interventions were the main reasons for the increase of requests, thus reflecting a real need for transcutaneous ultrasound exams in critical care practice.

4.2. Is a 3.5-Inch Screen Sufficient to Make Decisions or Guide Punctures?

The PersUS screen size raises concerns about image quality [19], although similar devices have been demonstrated to provide the same accuracy in cardiac sonoanatomy (endo-/pericardial effusion) as high-end echocardiography [20, 21]. We observed a highly reliable image quality for evaluation of effusions and basic cardiac
Table 2: Indications for clinical context-based ultrasound requests within routine ward rounds without or with personalized ultrasound (PersUS). Randomized determination of availability of PersUS. Group A did not receive ultrasound within a ward round and indications regularly determined a systematic echocardiography in a laboratory. In contrast, Group B received personalized ultrasound during the ward round.

<table>
<thead>
<tr>
<th>Category number</th>
<th>Indication for request of a focused exam within ward round</th>
<th>Group A</th>
<th>Group B</th>
<th>Total</th>
<th>Decision for referral to echo lab Group A versus B</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients in ward round</td>
<td></td>
<td>473</td>
<td>534</td>
<td>1007</td>
<td>95 versus 12</td>
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<tr>
<td>No. of patients receiving indications for echocardiography</td>
<td>95</td>
<td>99</td>
<td>194</td>
<td>95 versus 12</td>
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</tr>
<tr>
<td>1</td>
<td>Focused echo (1)</td>
<td>22</td>
<td>16</td>
<td>38</td>
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<tr>
<td>2</td>
<td>EF of both ventricles</td>
<td>41</td>
<td>37</td>
<td>78</td>
<td>41/6</td>
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<tr>
<td>3</td>
<td>Pleural effusion (both hemithoraces) including quantification</td>
<td>37</td>
<td>42</td>
<td>83</td>
<td>37/4</td>
</tr>
<tr>
<td>4</td>
<td>Ascites, marking for later puncture or puncture (2)</td>
<td>11</td>
<td>8</td>
<td>18</td>
<td>11/1</td>
</tr>
<tr>
<td>5</td>
<td>Valve function (3)</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>3/2</td>
</tr>
<tr>
<td>6</td>
<td>Mitral insufficiency (focused assessment prior TOE)</td>
<td>4</td>
<td>0</td>
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<tr>
<td>7</td>
<td>Resuscitation (FEEL protocol)</td>
<td>0</td>
<td>1</td>
<td>1</td>
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<td>8</td>
<td>Urinary bladder filling state, postrenal failure</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>9</td>
<td>Pericardial effusion (exclusion, or size and clinical course)</td>
<td>22</td>
<td>18</td>
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<tr>
<td>10</td>
<td>Pulmonary valve replacement, postinterventional check</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>2/0</td>
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<tr>
<td>Indications total</td>
<td>133</td>
<td>134</td>
<td>267</td>
<td>133/14</td>
<td></td>
</tr>
</tbody>
</table>

(1) Combined focused TTE including EF, oriented valve morphology and function, left and right ventricular dimensions. Clinical contexts contained focus on hypertension (LV-hypertrophy), right heart pressure overload, NSTEMI (LVEF), atrial fibrillation (valves, LVEF), postintervention (EF, pericardial effusion), pulmonary vein isolation therapy in case of atrial fibrillation (EF, pericardial effusion).

(2) Including 3 cases per group of the request soft tissue or musculoskeletal assessment for hematoma in the groin after coronary angiography or after pacemaker/defibrillator implantation in the anterior chest or shoulder area.

(3) Main issues were focalized assessment of aortic valve opening in the elderly.

anatomy and function in critical care. Our data suggests that the size itself has little impairment on decision making in real time. In agreement with recent studies of the same type of device [20, 21] we found that this quality was sufficient for real-time punctures of various targets. However, for more advanced examinations, such as diastolic function, MobUS seems to be the better choice.

4.3. Time Constraints. One concern of PersUS integration in our study was the investment of up to 10 minutes per ultrasound exam. Time is an essential component in acute care. Early application of ultrasound has been shown to reduce the number of viable diagnoses in the emergency setting [9] and determine outcome [13, 16, 17, 22], leading to calls for documentation of focused ultrasound examination length [18]. For goal-directed echocardiography, mean acquisition time was 10.5 ± 4.2 min [23]. Duration depends on the type of focused exam [3] and the body region (cardiac, lung, abdomen, and multiple regions). Exam times can vary from seconds up to 10 min [23–30]. The screening capability of PersUS allows effusions, for example, to be examined faster in triage [12, 13, 26] or within Advanced Life Support (maximum 10 seconds for a subxiphoidal view) during pauses between chest compressions [25]. In contrast, it was estimated that the comprehensive cardiac or abdominal exams would take more than 20 min [4, 18, 29, 31]. Although we found similar results in our substudies of cardiac diagnostic ultrasound, the integration of a quick-check ultrasound exam such as the one in the acute setting was considerably faster. The PersUS exam in our study was not restricted to cardiac indications [30], contained fewer than 5 questions per patient, and required much less time than was expected [32].

4.4. Future Remarks. We suggest combining the physical and PersUS exams into a standard clinical exam protocol [33]. This would yield increased implementation in the clinical context of acute and critical care medicine and cost-effective analysis as calculated for other settings [34–36].

4.5. Limitations. Due to the prospective design and the broad number of patients examined in different substudies and hospitals, we did not have the possibility to review all
examinations by blinded experts. In addition, blinding of the pictures/movies according to the US device was technically not possible. Therefore, comparison between different US devices might be subjective according to the examiners observation. Moreover, this study does not intend to suggest that focused and personal ultrasound examinations are sufficient to understand the patient’s complete physiological state. Complete evaluation of dyspnoea, for example, requires comprehensive echocardiography [18]; however, this is rarely achievable in all critical care units in real time, leaving the treating physician to obtain additional information for a specific clinical problem before the more specialised practitioner is involved. Our study required neither comparison with findings using a standard ultrasound machine and a comprehensive exam nor confirmation of findings from a second expert sonographer. It is not generalisable to other hospitals. However, there is, to our knowledge, no existing gold standard for focused ultrasound combined with clinical examination.

5. Conclusions and Key Message

The integration of personalized ultrasound in the daily acute and critical care workflow is safe and easily applied to patient admissions, routine procedures, and ward rounds with little additional time requirement. It will accelerate and improve decision making and interventions. We propose the development of novel ultrasound-based clinical pathways, standard operation procedures, and workflow protocols by integration of PersUS.

Abbreviations

ED: Emergency department
PersUS: Personalized ultrasound
MobUS: Mobile ultrasound.

Conflict of Interests

The authors have no conflict of interests to declare.

Authors’ Contribution

Raoul Breitkreutz planned the study and analyzed the data. Marco Campo dell’Orto (substudies 1 and 2), Peter M. Zechner (substudy 3), and Florian H. Seeger (substudy 4) were responsible for study planning and execution, participated in the respective substudy protocols, and completed data acquisition. Tanja Stenger checked statistical accuracy. Felix Walcher provided oversight to the study. Raoul Breitkreutz drafted the paper, which was revised by Marco Campo dell’Orto, Florian H. Seeger, Felix Walcher, Peter M. Zechner, and Colleen Cuca and reviewed and approved by all the coauthors. Raoul Breitkreutz and Marco Campo dell’Orto contributed equally to the study.

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References


Clinical Study

Reducing Radiation Dose in Emergency CT Scans While Maintaining Equal Image Quality: Just a Promise or Reality for Severely Injured Patients?


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Objective. This study aims to assess the impact of adaptive statistical iterative reconstruction (ASIR) on CT imaging quality, diagnostic interpretability, and radiation dose reduction for a proven CT acquisition protocol for total body trauma.

Methods. 18 patients with multiple trauma (ISS ≥16) were examined either with a routine protocol (n=6), 30% (n=6), or 40% (n=6) of iterative reconstruction (IR) modification in the raw data domain of the routine protocol (140kV, collimation: 40, noise index: 15). Study groups were matched by scan range and maximal abdominal diameter. Image noise was quantitatively measured. Image contrast, image noise, and overall interpretability were evaluated by two experienced and blinded readers. The amount of radiation dose reductions was evaluated.

Results. No statistically significant differences between routine and IR protocols regarding image noise, contrast, and interpretability were present. Mean effective dose for the routine protocol was 25.3±2.9 mSv, 19.7±5.8 mSv for the IR30, and 17.5±4.2 mSv for the IR40 protocol, that is, 22.1% effective dose reduction for IR30 (P = 0.093) and 30.8% effective dose reduction for IR40 (P = 0.0203). Conclusions. IR does not reduce study interpretability in total body trauma protocols while providing a significant reduction in effective radiation dose.

1. Introduction

The use of computed tomography (CT) brought enormous benefits to modern medicine and diagnostic CT examinations are increasingly used in recent years because of their speed, availability, and diagnostic power. In particular, for patients with polytrauma during the early resuscitation phase, whole-body CT is recommended as the standard diagnostic modality [1]. However, the common utilization of CT is accompanied by a steady increase in the population's cumulative exposure to ionizing radiation [2, 3]. As X-rays have been classified as “carcinogen,” new efforts to minimize radiation exposure were undertaken to meet rising concerns of possible long-term cancer, especially regarding pediatric and young patients as well as patients undergoing several follow-up CT examinations [4]. A plurality of approaches, from “AEC” (automated exposure control) to “X-ray beam collimation,” led to a significant reduction in radiation dose [5, 6]. With the fast advancement of computational power, the technique of iterative reconstruction (IR), well known from SPECT and PET imaging, became the center of attention for CT adaption in recent years [7–10].

The group of severely injured patients is of great concern for dose reduction as these patients may be of a young age and standard protocols for emergency settings use relatively high radiation doses in order to detect subtle but possibly life-threatening lesions [11]. As recently demonstrated, IR algorithms do not significantly delay CT imaging time in an emergency setting [12], though the impact of IR on image quality and dose reduction has not been investigated.

The working hypothesis was that the use of IR algorithms would reduce effective radiation doses without affecting
image quality and interpretability in comparison with routine CT imaging based on filtered back projection (FBP). Therefore this study aimed to prospectively evaluate different levels of IR algorithms on imaging quality and dose reduction for a proven CT full body trauma protocol.

2. Materials and Methods

2.1. Study Design. The study was carried out prospectively. The study design was approved by the institutional ethics board. The need for informed consent was waived as patients were not exposed to an additional radiation dose and patient data was anonymized. The study was conducted at a university teaching hospital.

All examined patients were classified as severely injured patients (injury severity score (ISS) ≥16) by the emergency department and underwent CT scans within the scope of the routine in-house algorithm for patients with severe and multiple injuries in accordance with the currently valid guideline [13]. At the time of study analysis, 10 patients were examined with IR 30 and 16 patients with IR 40 protocol. For matching the patients in all three patient groups (FBP, IR 30, and IR 40) these patients were compared by scan range and maximal abdominal diameter. Subsequently, some patients had to be excluded and 6 patients per group were enrolled in the final statistical analysis (age = 53.9 ± 19.9 years, 5 females). All groups were matched manually as to scan range and maximal abdominal cross-section area to attain a homogenous study collective. The authors regarded this approach to be a more accurate approximation for full body radiation exposure of the study group than traditional parameters, that is, BMI [14]. The control group was examined with the routine filtered back projection (FBP) protocol whereas the protocol for the first study group, performed on the same CT scanner, consisted in 30% adaptive statistical iterative reconstruction (ASIR) application in the raw data material. After a preliminary assessment of the newly acquired image quality and positive results in terms of interpretability, a stronger level of IR (40) was implemented on the standard protocol and performed on the second study group.

2.2. CT Protocol. All patients were examined using a 64-slice multidetector CT scanner (Lightspeed VCT, GE Healthcare, USA). The emergency protocol consists of two separate scans. The first is an axial scan of the cranium, angulated between 0° and 30° (depending on the positioning of the patient) without injection of a contrast agent (CA) in order to detect possible intracranial bleeding.

Second, after application of CA (see Section 2.3) a helical scan of the whole body is performed in cranio-caudal direction, ranging from above the frontal sinus (in order to picture the cerebral arterial circle) to the bottom of the pelvis. Image acquisition is conducted with the following parameters: tube voltage: 140 kV, collimation: 40, pitch: 1.375, and noise index: 15.

The protocol of the axial cranium scan was not modified. If additional scans were performed due to individual injury patterns, these have not been considered and were excluded from the image quality and radiation dose analyses.

2.3. Injection Table. For the helical whole-body spiral 140 mL of CA was administered in a split bolus technique:

100 mL CA (2 mL/s flow rate),
Figure 2: Image acquisition with the routine CT protocol reconstructed by filtered back projection (FBP) without IR. In (a) the white arrow points to a small pneumothorax in the lingula segment. In (b) a hepatic laceration in liver segments 2 and 4a is displayed. Notice the semicircular soft tissue emphysema on the right side. In (c) the arrow points to the fracture of the left transverse process of L3 with no major dislocation and a corresponding haematoma of the psoas muscle.

20 mL saline (1 mL/s flow rate),
60 mL CA (4 mL/s flow rate),
40 mL saline (4 mL/s flow rate).

The CT scan starts with a delay of 85 seconds after first injection of the 100 mL CA.

Using this technique, an additional scan and radiation dose can be avoided as arterial and venous contrasting is depicted in the same scan. The nonionic, low osmolality contrast medium iobitridol (Xenetix 350, Guerbet GmbH, Germany) was utilized as CA.

2.4. Data Reconstruction. IR algorithms attempt to overcome elevated image noise and artifacts resulting from reduced voltage and current. The adaptive statistical iterative reconstruction (ASIR) technique attempts to accurately rebuild images by concentrating on noise reduction [15]. It therefore uses information obtained from the FBP algorithm as an initial building block for image reconstruction. The ASIR model then uses matrix algebra to transform the measured value of each pixel \( y \) to a new estimate of the pixel value \( y' \). This pixel value is then compared with the ideal value that the noise model predicts. This process is repeated in successive iterative steps until the final estimated \( X \) and ideal pixel values ultimately converge [16, 17]. Using this method, IR algorithms are able to selectively identify and then subtract noise from an image.

The image acquisition was modified by 30% (40%) use of IR in the raw data domain. Due to computational limitations the raw data material is then first computed into slices of 5 mm thickness in order to deliver a fast summary of the patient for diagnostic assessment and subsequently into slices of 0.625 mm thickness. The image reconstruction of the 5 mm slices used the same level of ASIR algorithms (30/40) as those of the raw data whereas the thin slices were both computed with 60% ASIR to further reduce image noise. No change of radiation dose is linked to the reconstruction ASIR.

2.5. Data Analysis. Quantitative analysis of image quality was evaluated for noise, that is, the standard deviation (SD) of attenuation value. Therefore a region of interest (ROI) was drawn as large as possible in the supraca rinal trachea without exceeding the lumen. Qualitative analysis of the acquired images was performed by two experienced and blinded radiologists in consensus. The images were cleared of all technical information in order to reduce expectation bias.
Figure 3: Image acquisition with the IR 30 protocol. In (a) the arrow points to a major ventral pneumothorax of the right lung. In the dorsal area there is pleural effusion with adjacent dystelectasis. In (b) a subtle laceration of the ventral splenic pole is marked by the arrow. Similar to the FBP protocol in Figure 1, a fracture of a transverse process of L4 without major dislocation can be diagnosed on the right side.

Image quality was evaluated in five categories: noise, contrast, artifacts, detectability of small structures, and overall diagnosability. Each category was evaluated by using a five-point Likert scale with 5 representing the best possible result and 1 insufficient results, for example, for overall diagnosability: (1) nondiagnostic image quality, (2) severe blurring with uncertainty about the evaluation, (3) moderate blurring with restricted assessment, (4) slight blurring with unrestricted diagnostic image evaluation possible, and (5) excellent image quality, no artifacts.

2.6. Statistical Analysis. The data were analyzed using SPSS 18.0 (SPSS Inc., Chicago, Ill). Radiation doses and image quality parameters were compared using the Mann-Whitney-U test. A P value of less than 0.05 was considered a statistical significance.

3. Results

3.1. Image Quality. Quantitative analysis for image noise (region of interest in the supracarinal trachea) yielded the following results: the standard deviations of attenuation value measured in HU were 3.9 ± 0.7, 3.4 ± 0.8, and 3.3 ± 0.6 for the routine, IR 30, and IR 40 protocol. There were no significant differences between the three groups.

Qualitative analysis yielded the following results: all (n = 18) CT examinations were estimated to be of excellent image quality without artifacts compromising diagnosability (level 5) in terms of image artifacts, detectability of small structures, and overall diagnosability (Figures 1, 2, 3, and 4). Regarding image noise and image contrast, no statistically significant differences resulted, with image noise estimated at 4.7 ± 0.5, 5 ± 0, and 4.8 ± 0.4 for the FBP, IR 30, and IR 40 protocol. For image contrast the results were 5 ± 0, 4.8 ± 0.4, and 4.8 ± 0.4, respectively. There were no significant differences between the three groups.

3.2. Radiation Dose. To estimate the effective radiation dose, first the CT volume dose index (CTDIvol) and the dose-length product (DLP) were obtained from the electronically stored dose report of each performed CT scan. The effective radiation dose was then calculated by multiplying the DLP by a conversion coefficient k of 0.017 mSv/mGy·cm [18]. See Table 1 for an overview of the radiation dose. The mean effective dose for the standard FBP protocol was 25.3 ± 2.9 mSv; the implementation of IR 30/30 resulted in 19.7 ± 5.8 mSv and
Figure 4: Image acquisition with the IR 40 protocol. In (a) the white arrows mark the bipulmonary contusions. The black arrow tags the mediastinal emphysema. In (b) the white arrow marks a subtle splenic laceration in the dorsal pole similar to the splenic lesion in Figure 3(b). Finding of a vertebral body fracture in (c) after a motorcycle accident. No accompanying lesion of the pancreas could be found.

<table>
<thead>
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<th>Table 1: Radiation dose.</th>
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<td>Max. abdominal cross-section</td>
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<tr>
<td>Sagittal (cm)</td>
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<tr>
<td>CTDIvol (mGy·cm)</td>
</tr>
<tr>
<td>DLP (mGy/cm)</td>
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<td>Effective radiation dose (mSv)</td>
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</table>

Parameters of the routine FBP protocol, IR 30 protocol, and IR 40 protocol. Data are presented as mean ± standard deviation. CTDIvol: CT volume dose index, DLP: dose-length product.

in 17.5 ± 4.2 mSv for IR 40/40 protocol, that is, 22.1% effective dose reduction for IR 30 ($P = 0.093$) and 30.8% effective dose reduction for IR 40 ($P = 0.0203$). See Figure 5 for an overview of the dose reduction.

4. Discussion

After its introduction in 1973, computed tomography (CT) was fast accepted by the medical community. In particular in the treatment of severely injured patients its diagnostic accuracy brought immense benefits and whole-body CT scans have become an integral part of the Advanced Trauma Life Support (ATLS) in multiple trauma centers. As several multicenter studies showed, whole-body CT scans in the early phase of treatment resulted in a significant increase of survival [1, 18, 19]. Hence, benefits of CT in an emergency setting outweigh by far the downsides with exposure to ionizing radiation being the most critical disadvantage. With a median cumulative effective dose as high as 40.2 mSv for CT scans of blunt trauma patients [11], efforts to reduce effective radiation doses still constitute a primary objective. Since the first introduction of IR algorithms into CT imaging there have been numerous studies regarding image quality, noise, and radiation dose reduction [20–22]. The overall findings, depending on the study design, proved either a significant dose reduction, a better image quality, or both. However, the applicability of these algorithms to an emergency setting has not yet
been examined, as image quality is of the highest priority in these circumstances.

With our findings being a first evaluation of the impact of IR algorithms in an emergency setting, a number of issues have to be addressed in the future. It has been shown in the literature that the mean effective dose for full body CT examinations ranges between 14 and 21 mGy whereas the mean effective dose in the control group of our study was 25 mGy [23]. The effective radiation dose is slightly above average as we used 140 kV for the routine trauma protocol. This is based on the fact that as a national center of maximum care we are confronted by a tendency to receive more complex severely injured patients than other institutions and image quality is paramount. After careful considerations of advantages and disadvantages, our institution decided to apply 140 kV for the routine whole-body trauma protocol, as this protocol is more robust concerning artifacts from foreign bodies (e.g., equipment from anesthetic intensive care). Of course, the use of a protocol with 120 kV is also appropriate. It can be assumed that the implementation of 120 kV for whole-body protocols instead of 140 kV will lead to a further reduction in radiation dose. The impact of IR on a 120 kV protocol has to be addressed in future studies.

As mentioned earlier, we first implemented an IR level of 30% in the protocol to ensure an excellent image quality and only afterwards modified the protocol to ASIR 40. As our study demonstrates there is no compromise to the diagnosability and it seems justifiable to investigate the implementation of ASIR 50 (representing the highest level of ASIR) to whole-body protocols in an emergency setting.

As stated above, the full body trauma protocol consists of two scans, an axial cranium scan and a helical body spiral. In this study only the latter was modified with IR algorithms as to our knowledge the impact of IR algorithms on the image quality for the neurocranium has not yet been evaluated outside an emergency setting. Nonetheless, mean DLP for routine protocols was 2273.0 mGy-cm, whereas mean DLP for the helical spiral was 1491.4 mGy-cm, thus accounting only for about 66% of total radiation dose; that is, axial cranium scans account for about one-third of radiation dose. Whether or not IR algorithms are applicable for cranium scans has to be investigated by future studies.

4.1. Limitations. With this study designed to be a feasibility evaluation of IR algorithms in an emergency setting, the major limitation naturally consists in the small number of patients examined. Secondly, there is no possibility of intra-individual comparison of image quality and radiation dose. This obstacle could be limited with a manually selected study group with respect to scan range and abdominal cross-section diameter. Nonetheless, a series of validity impairments, that is, limitations in the positioning of patients, foreign bodies in the FOV, etcetera, may have resulted in increased radiation doses due to beam-hardening artifacts.

Thirdly, the small study group did not allow for evaluation of similar injury patterns. Fourthly, as the sole parameter for objective image quality, we only assessed the image noise. Further studies have to be performed in a larger patient collective investigating different contrast-to-noise ratios.

5. Conclusions

In these preliminary results, the use of IR algorithms is a promising application to reduce radiation exposure without compromise to the radiological interpretability, even in an emergency setting where image quality is paramount.

Conflict of Interests

The authors declare that they have no relevant conflict of interests to disclose.

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References


Research Article

Thorax, Trachea, and Lung Ultrasonography in Emergency and Critical Care Medicine: Assessment of an Objective Structured Training Concept

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Background and Study objective. Focused lung ultrasound (LUS) examinations are important tools in critical care medicine. There is evidence that LUS can be used for the detection of acute thoracic lesions. However, no validated training method is available. The goal of this study was to develop and assess an objective structured clinical examination (OSCE) curriculum for focused thorax, trachea, and lung ultrasound in emergency and critical care medicine (THOLUUSE).

Methods. 39 trainees underwent a one-day training course in a prospective educational study, including lectures in sonoanatomy and -pathology of the thorax, case presentations, and hands-on training. Trainees’ pre- and posttest performances were assessed by multiple choice questionnaires, visual perception tests by interpretation video clips, practical performance of LUS, and identification of specific ultrasound findings.

Results. Trainees postcourse scores of correct MCQ answers increased from 56 ± 4% to 82 ± 2% (mean ± SD; P < 0.001); visual perception skills increased from 54 ± 5% to 78 ± 3% (P < 0.001); practical ultrasound skills improved, and correct LUS was performed in 94%. Subgroup analysis revealed that learning success was independent from the trainees’ previous ultrasound experience.

Conclusions. THOLUUSE significantly improves theoretical and practical skills for the diagnosis of acute thoracic lesions. We propose to implement THOLUUSE in emergency medicine training.

1. Introduction

Focused lung ultrasound (LUS) examinations are increasingly important diagnostic tools in emergency and critical care medicine [1–4]. A broad area of medicine, including internal medicine [5, 6] and traumatology [1, 7], can benefit from its time and cost-effectiveness and absence of radiation exposure, as well as the reduction of need for transportations...
of ventilated patients. Using portable ultrasound devices, LUS is now available in virtually all in- and out-of-hospital scenarios [8].

However, unlike focused assessment with sonography in blunt trauma (FAST) that has become a standard procedure, ultrasound examination of thorax and lungs has only recently been established for workup of critically ill patients [9]. Still, when a lesion is suspected, chest X-rays (CXR) or CT scans remain the diagnostic procedures of choice. Apart from echocardiography, noninvasive examination of the chest by ultrasound is not routinely performed in most centers although many investigations support its use [4, 10, 11].

While the detection of fluid such as in hemathorax or pleural effusion (PLE) has been described as relatively simple [12] and ultrasound-guided thoracocentesis can be safely performed in ventilated patients [5], sonographic diagnosis of pneumothorax (PTX) represents a challenge to most examiners. Using a panel of previously validated ultrasound findings and artifacts, for example, absence of lung sliding and comet tails [13, 14] or presence of lung point phenomenon in the M-mode scan, it was demonstrated that diagnosis of PTX could be achieved in real time and with high sensitivity and specificity [4, 15, 15, 16]. There is evidence that LUS allows reliable detection of PTX under conditions (e.g., prehospital) where CXR or CT is not available [1].

To our knowledge, no focused training method for chest sonography, particularly for the use in emergency situations, has been validated until today.

Therefore, we designed an objective structured clinical examination (OSCE) [17] training concept for focused thorax, trachea, and lung ultrasound in emergency and critical care medicine (THOLU/USE). In the present study, we aimed to test if our training concept can improve (1) factual knowledge of theoretical background, (2) visual perceptive skills, and (3) practical imaging performance, that is, the ability to steer the ultrasound probe [18], obtain reproducible image scans, and interpret structures or artifacts during ultrasound examination of the chest.

2. Materials and Methods

2.1. Study Design. We performed a prospective educational study with a standardized OSCE curriculum. A total of 54 trainees were enrolled into the program in 4 independent training days. Group A included fourteen medical students (age 25 ± 2 years (mean ± standard deviation)) and group B thirty-two anesthesiologists (32 ± 5). Both groups had none or very limited ultrasound knowledge. Group C consisted of eight trauma surgeons (37 ± 6), who all previously underwent a FAST training [19]. Instructors were ultrasound-trained pulmonologists (n = 3), internists (n = 3), cardiologists (n = 4), anesthesiologists (n = 2), and trauma surgeons (n = 2). Medical interns (n = 3) were specifically trained to give instructions for use of ultrasound phantoms. A formal institutional review board approval was obtained at the University of Frankfurt, Medical faculty. All trainees gave informed consent for anonymous analysis of their test results. Patients or relatives of ventilated patients gave their informed consent to serve for teaching purposes according to local ethical standards at our institution.

2.2. Course Curriculum and Training System. Theoretical training was scheduled for 2.5 hours and included six brief lectures of anatomy, physiology, and pathology of the thorax, as well as four case presentations on clinical scenarios related to PLE and PTX (Table 1). Practical training was scheduled for 2.5 hours and included two units of hands-on training (HOT), following modifications of previously described OSCE protocols [20, 21]. In HOT-1, each trainee had to pass six and in HOT-2 seven different thematic stations (Table 2). There was a strictly organized circuit system between the HOT stations. The ratio of instructor per station and trainee was 1:1 and 1:2 offering each trainee at least 5 min of training per station. Each instructor gave a short introduction to the specific objective of the station, followed by a one-minute demonstration of the standardized sonographic views or procedures. In total, twelve major sonographic views or artifacts were studied in healthy models. The same healthy models were used in HOT-1 and -2, but views and structures alternated between individuals. Two stations in HOT-2 included patients with selected pathologies (Table 2). Patients with chronic or malignant lung disease were included to demonstrate PLE; patients that recently underwent sterno- or thoracotomy due to cardiac or pulmonary disease were used to demonstrate PTX. Both HOT-1 and HOT-2 included one virtual station, where typical pathologic findings and artifacts were demonstrated in the form of electronic pictures and video clips on a laptop computer (Table 3).

2.3. Phantoms and Ultrasound Equipment. In order to support the trainees active learning process, we included custom made gel phantoms into the HOTs. Gel was made by commercially available pork skin leafs (Dr. Oetker Nahrungsmittel, Bielefeld, Germany). Phantoms were prepared with 20 grams (equivalent to 12 pieces) of gelling leafs per half a litre of distilled water, carefully heated to 60°C, followed by stirring for 1 min. Next, gels were casted into plastic containers (95 x 15 x 15 cm) and allowed to cool down for two hours at room temperature. While still viscous, water and content filled rubber balloons were carefully submerged in the gel body by avoiding insertion of air bubbles. Next, gels were incubated in a refrigerator overnight until solid. Stiff gel phantoms were used without antimicrobiological additives for 10 days. In HOT-1, one station contained a series of rubber balloons. Each balloon was filled with specific contents empirically chosen to mimic typical phenomena found in chest ultrasound: (a) pure water to visualize transmission and reflexion of ultrasound on interfaces with different acoustic impedance, for example, thorax wall, pleural line, and PLE; (b) air to mimic reverberation artifacts found in PTX; (c) parboiled rice grains and starch to mimic partially consolidated PLE and fibrinous structures; (d) olives as substitute for soft but solid tissues; (e) a stone as substitute for carbon-rich structures such as bones with complete ultrasound absorption and dorsal extinction. Finally, balloons with small jelly babies sized less than 1 cm and a tiger duck made of
<table>
<thead>
<tr>
<th>Program number and time limit</th>
<th>Lecture, case presentation, or HOT&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Content and key messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (15 min)</td>
<td>Reasons for thorax, trachea, and lung ultrasonography in emergency and critical care medicine</td>
<td>Introduction, context, advantages, and disadvantages of chest ultrasound in emergency and critical care medicine</td>
</tr>
<tr>
<td>2 (15 min)</td>
<td>Sonoanatomy of the thorax, trachea, and lung</td>
<td>Brief physics of US, probes, chest wall and organ anatomy, general remarks on B-mode of structures, basic windows and artifacts, and impact on views of artificial ventilation</td>
</tr>
<tr>
<td>3 + 4 (10 min + 5 each)</td>
<td>Two related clinical case presentations from the emergency department (incl. 10 min discussion)</td>
<td>Authentic clinical example, well prepared with original US sequences, relevant PLE, and rib/sternal fracture</td>
</tr>
<tr>
<td>5 (20 + 10 min)</td>
<td>US of PLE: phenomena and artifacts (incl. 10 min discussion)</td>
<td>Repetition of basic windows and artifacts, B-Mode, and appearance and differential diagnosis of hypoechoic findings (pulmonary embolism, fluids, chest hematoma, and lung contusion)</td>
</tr>
<tr>
<td>(90 min)</td>
<td>HOT-1</td>
<td>Practical training with instructors and models</td>
</tr>
<tr>
<td>6 (15 min)</td>
<td>US of trachea, cartilages, and cricoids: sonogram and artifacts</td>
<td>Air artifacts, reverberation, and procedural ultrasound use within percutaneous dilatational tracheotomy</td>
</tr>
<tr>
<td>7 (20 + 10 min)</td>
<td>US of pneumothorax: sonogram and artifacts (incl. 10 min discussion)</td>
<td>Views of air artifacts, reverberation, loss of pleural sliding and comet tails, lung pulse, and understanding M-mode sonograms</td>
</tr>
<tr>
<td>8 (15 min)</td>
<td>Standardized sequence of lung ultrasonography</td>
<td>How to quickly examine a patient with suspected PLE or PTX. Algorithm training with practical relevance for time sensitive scenarios.</td>
</tr>
<tr>
<td>9 + 10 (10 min + 5 each)</td>
<td>Two related clinical case presentations from intensive care medicine (incl. 10 min discussion)</td>
<td>Physiology of lung US in intensive care medicine, postprocedural (insertion of central line), postcardiotomy PTX despite tube drain</td>
</tr>
<tr>
<td>(90 min)</td>
<td>HOT-2</td>
<td>Practical training with instructors and models</td>
</tr>
</tbody>
</table>

<sup>a</sup>Lectures and cases all included a brief discussion; all major artifacts were taught in a clinical context. Lectures were followed by hands-on trainings (HOT). PLE: pleural effusion; PTX: pneumothorax; US: ultrasound examination.

2.4. Course Assessment. For scientific evaluation of the THOLUUSE program, trainees had to pass three types of tests: (a) a theoretical test with multiple-choice questions (MCQs) before (precourse) and after (postcourse) completion of the program. Each MCQ test set contained fifteen textural questions and five questions with scanned ultrasound pictures where specific sonoanatomical structures had to be identified. The maximum time to answer each question was 60 seconds. As one of the posttests, (b) a recognition quiz to test the visual perception skill with fifteen video clips (see Appendix Table 1 in Supplementary Material available online at http://dx.doi.org/10.1155/2013/312758), each loop had a duration of 10 seconds followed by a 5-second break to note the results onto a standardized answering form. A self-running DVD was produced with MAGIX 5.5 deluxe (MAGIX AG, Berlin, Germany). The DVD was started once and ran continuously without replay or break until all video clips were shown. The order of the clips, questions, and answers for postcourse testing was changed in a randomized fashion to prevent memory of order or answers. Finally,
Table 2: Stations and learning targets of hands-on training (HOT) stations.

<table>
<thead>
<tr>
<th>Station no.</th>
<th>HOT-1/HOT-2</th>
<th>Training: station topic</th>
<th>Model/patient and position</th>
<th>Content/learning issue</th>
<th>Scan mode B/M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(HOT-1)</td>
<td>Thorax</td>
<td>Model, sitting</td>
<td>Thorax, ribs, bone, cartilage, and sternum</td>
<td>B</td>
</tr>
<tr>
<td>2</td>
<td>(HOT-1)</td>
<td>Pleura</td>
<td>Model, supine</td>
<td>Lung sliding, B-lines</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>(HOT-1)</td>
<td>Differential diagnosis</td>
<td>Model, supine</td>
<td>Lung, lateral and posterior axillary lines, liver, spleen</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>(HOT-1)</td>
<td>Ultrasound phantom</td>
<td>—</td>
<td>Training on gel-embedded artifacts in rubber balloon US-phantoms</td>
<td>B</td>
</tr>
<tr>
<td>5</td>
<td>(HOT-1/2)</td>
<td>Trachea</td>
<td>Model, supine</td>
<td>Trachea, central and subcutaneous vessels, cricoid cartilage, and thyroid gland</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>(HOT-1/2)</td>
<td>“Virtual” station</td>
<td>Laptop, screen</td>
<td>12 pictures divided in HOT-1 and HOT-2 with or without pathologies, explained by instructor</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>(HOT-1/2)</td>
<td>US sequence</td>
<td>Dummy and model, supine</td>
<td>Training of sequence on manikins (HOT-1) and models (HOT-2)</td>
<td>B</td>
</tr>
<tr>
<td>8</td>
<td>(HOT-2)</td>
<td>Advanced lung- and pleural US</td>
<td>Model, supine</td>
<td>Apnea, “lung pulse” and “seashore” sign</td>
<td>B/M</td>
</tr>
<tr>
<td>9</td>
<td>(HOT-2)</td>
<td>Advanced lung US</td>
<td>Patient sitting/supine</td>
<td>Training with patient and pathology (atelectasis, PLE, or PTX)</td>
<td>B/M</td>
</tr>
<tr>
<td>10</td>
<td>(HOT-2)</td>
<td>US sequence</td>
<td>Patient, supine</td>
<td>Training of algorithm and sequence with patient and pathology (atelectasis, PLE, or PTX)</td>
<td>B/M</td>
</tr>
<tr>
<td>11</td>
<td>(HOT-2)</td>
<td>Puncture phantom</td>
<td>—</td>
<td>Pleural effusion, puncture gel phantom</td>
<td>B</td>
</tr>
</tbody>
</table>

Table 3: Learning targets of the "virtual station" within the hands-on training (HOT).

<table>
<thead>
<tr>
<th>Picture number</th>
<th>Related topic</th>
<th>Mode (B/M)</th>
<th>Details to recognize</th>
<th>Difficulty level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal and edema</td>
<td>B</td>
<td>A-line, reverberation artifacts, multiple B-lines</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Normal</td>
<td>B</td>
<td>Peritoneum, kidney, and bony rib artifact with posterior acoustic shadowing</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Fluid differential diagnosis</td>
<td>B</td>
<td>Four B-mode views of fluids: subdiaphragmatic fluid and liver, ascites, spleen, diaphragm, PLE, lobe atelectasis, diaphragm and liver, and ascites and small bowel</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>PLE</td>
<td>B</td>
<td>Spleen, fluid, and compression atelectasis</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>PLE/ascites</td>
<td>B</td>
<td>Small amounts of PLE, diaphragm, and ascites</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Acoustic shadowing, anatomy and, stone</td>
<td>B</td>
<td>Liver and hyperechogenic diaphragm, gall bladder and stone with posterior acoustic shadowing</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>PLE, M-mode appearance</td>
<td>B and M</td>
<td>Small PLE, multiple comet tails, A-line, and separated visceral pleura</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>PLE</td>
<td>B</td>
<td>Large amount of PLE, good view of diaphragm and spleen</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Peripheral pulmonary embolism</td>
<td>B</td>
<td>Visible triangular break in visceral pleural line due to peripheral pulmonary embolism, lung tissue</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Lung pulse, normal M-mode</td>
<td>B and M</td>
<td>Reverberation artifacts of pleural line, lung pulse, sonoanatomical finding of &quot;seashore&quot; sign in the M-mode</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Stratosphere sign</td>
<td>B and M</td>
<td>Multiple reverberation artifacts, pleural line</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Lung point</td>
<td>B and M</td>
<td>Breakup of pleural line (change point between seashore/stratosphere sign)</td>
<td>2</td>
</tr>
</tbody>
</table>

PLE: pleural effusion; PTX: pneumothorax; US: ultrasound examination.
at the end of HOT-2, there was (c) a practical postcourse examination in which trainees had to demonstrate their skills in correct positioning of the ultrasound probe and to visualize and identify sixteen predefined sonoanatomic items considered particularly relevant to chest ultrasound (see Appendix Table 2). Over 15 min, trainees performance was observed by an instructor and rated on a standardized score sheet. Instructors were not allowed to help or modify the positioning of the probe, and noted results were blinded to the participants. A cut-off level of 60% correctly performed tasks/identified structures was arbitrarily defined to passing before the onset of the study.

2.5. Statistical Analysis. Our null hypothesis was that training would not significantly increase trainees skills. A finding was considered significant when error probability was less than 5% and null hypothesis could be rejected. Results are
given as box plots, scatter plots, or mean and confidence intervals or standard deviation if not indicated otherwise. For comparison of the training effects of the different test groups, nonparametric Wilcoxon matched-pairs signed rank test (within groups) or Mann Whitney $U$-test (between groups) was applied. Originally, we had scheduled a precourse test for practical skills as well. However, we had to omit precourse testing because of insufficient knowledge and practical skills of most participants before entering the study. Therefore results of the postcourse test were computed against zero.

Test results are shown in two ways: (a) mean result of all trainees passing a test was regarded as general learning effect by examinees and (b) number of trainees who scored positive for a specific question or observation. The latter was interpreted as learning success on a specific item. Statistical analysis and figures were produced with GraphPad Prism software (San Diego, CA, USA).

3. Results

3.1. Assessment of Immediate Learning Effects. Medical students (group A), anaesthesiologist residents (group B), and trauma surgeons (group C) mean precourse scores of correct answers were 11.2 (10.5–13.1, 95% CI), 11.5 (9.8–13.1), and 11.8 (9.5–14.0), respectively. After completion of postcourse exams, all groups of trainees achieved comparable increases in their scores: A: 16.1 (15.2–16.1, $P < 0.001$ for comparison to precourse results), B: 17.1 (16.2–17.8, $P < 0.001$), and C: 16.8, (15.6–17.9, $P < 0.001$), respectively (Figure 3(a)). When MCQs were sorted according to the learning target of the course curriculum, the gain of theoretical knowledge in sonoanatomy, physiology, and pathology of the chest, particularly regarding PLE and PTX, was homogeneous in all groups (Figure 3(b)).

3.2. Recognition and Interpretation Skills. The ability of the trainees to evaluate a specific physiological or pathological ultrasound finding under pressure of time was tested by recognition and interpretation of video clips. The number of correct answers markedly increased from pre- to postcourse tests in all groups: group A from 7.9 (6.8–9.1) to 11.6 (10.8–12.5, $P < 0.001$ in comparison with precourse testing), in B from 8.5 (6.7–9.2) to 12.3 (10.3–13.2, $P < 0.001$), and in C from 9.1 (7.1–11.2) to 12.6 (11.4–13.9, $P < 0.01$), respectively (Figure 3(c)). When the scores were sorted by pathology, best results were obtained for detection of fluids. Following completion of the course program, most trainees were familiar with basic sonographic signs for detection of PTX as compared to normally inflated lungs by using both B- and M-mode, (Figure 3(d)).

3.3. Practical Imaging Performance. Testing more complex practical capabilities (i.e., steering the probe to a standardized anatomic position, obtaining a clear view, and identifying the sonoanatomical findings/artifacts), a mean of 95% of the postcourse sonograms was conducted in a technically correct fashion (Figure 4(a)).

Subgroup analysis of practical performance skills revealed no statistical significant differences of visualization and interpretation of distinct anatomic sites/learning items (Figure 4(b)).

4. Discussion

In the present study, we developed and assessed an OSCE-based training program for THOLUUSE. For more than a decade, FAST has been established as a standard procedure in shock rooms or emergency departments for early diagnosis of cavity bleeding in blunt trauma. Kirkpatrick et al. [1] suggested an extension of FAST (the so-called EFAST) to include sonographic detection of posttraumatic pneumothoraces in the algorithm. However, in the absence of appropriate teaching models and concepts, it remains challenging for an individual examinee to gain sufficient expertise for correct sonographic detection of PTX. Techniques of chest ultrasound, including PTX, have previously been described; however, the effectiveness of those instructions was never assessed and/or validated [1, 16, 22, 23].

It has been questioned if a one-day training course with a brief factual input and few essential exams can teach ultrasound skills that can be of practical relevance for the trainee [24]. It is well known that factual knowledge communicated by noninteractive lectures has only limited impact on gaining and keeping knowledge [25]. With respect to ultrasound examination, it seems rather unlikely that sufficient expertise can be gained from such lectures alone [23]. In the same token, Sisley et al. reported that simply assessing factual knowledge gives an incomplete picture of performance, and they observed low image interpretation skills in the ultrasound evaluation of trauma [23]. Therefore, in this study, we chose an OSCE-based approach that encourages active learning and practical performance. This method is also useful to assess different competencies and can identify/unmask areas with deficiencies that are of practical relevance [23].

Our results show that upon completion of a one-day LUS course participants were able to perform a standardized sonographic examination of the thorax and correctly identify and interpret the most relevant physiological and pathological findings, including PLE and PTX. Of note, we found no significant differences between medical students and postgraduates from different medical professions, and trainees postcourse performances were independent of previous levels of ultrasound experience. Our findings are supported by a project for experimental ultrasound learning, the Advanced Diagnostic Ultrasound in Microgravity (ADUM) [26], launched by the National Aviation and Space Agency (NASA). In this study, nonmedical astronauts were trained by On-board Proficiency Enhancer (OPE) software to send a sonogram to a remote ultrasound expert on earth [27]. The authors demonstrated that sufficient skills for technical conductance and image acquisition of ultrasound can be taught to ultrasound novices in a few hours [26]. Similarly, Bedetti et al. showed that recognition of B-lines is equally reliable whether an experienced or
Figure 3: (a) Theoretical learning results of individual trainees and test groups assessed with MCQ in a pre-course (Pre) and post-course (Post) testing. Box plots represent the 25th and 75th percentiles with median. Dashed line indicates an arbitrary defined pass level of 60%.

(b) Number of trainees who correctly answered MCQ. Each symbol represents an independent question sorted by related categories.

(c) Test for visual perceptive skills, where trainees had to identify characteristic physiologic or pathologic ultrasound findings, each shown in a 10 sec video clips. Dashed line indicates an arbitrary defined pass level of 60%.

(d) Numbers of trainees who obtained a correct answer during visual perceptive skill test. Each symbol represents a video-clip sorted by related categories.

A novice echocardiographer performed the exam [28]. For FAST, it has been shown that a 1-day training course allows trainees to perform a preclinical FAST with a high level of accuracy [19].

A limitation of this study was that postcourse performance of trainees could only be assessed shortly after completion of the program. Previous evaluations of FAST course programs demonstrated that trainees skills decreased as a function of time, particularly when ultrasound techniques were not practiced on a regular basis and further supervised teaching was not available [25]. Therefore, we and others currently are establishing a continuous educational program that combines modules for abdominal, heart, and thorax ultrasound in emergency and critical care medicine [29,30].

In this respect, the THOLUUSE concept proposed in this study was certified by the German Society of Ultrasound in Medicine (DEGUM) and incorporated substantially into a modular blended learning programme of the German Society of Anesthesiology and Intensive Care Medicine (DGAI) for official training in emergency and critical care medicine [31].
5. Conclusion

The results of our study demonstrate that a one-day training program like THOLUUSE significantly improves theoretical and practical skills for sonographic diagnosis of acute thoracic lesions, including PLE and PTX. Postcourse gain of competence was independent of previous ultrasound expertise of the trainees, and we propose to implement THOLUUSE in the training of medical emergencies. THOLUUSE long time impact on the management of patients in emergency and critical care medicine needs further investigation.

Abbreviations

FAST:  Focused abdominal sonography for trauma
LUS:  Lung ultrasound
HOT:  Hands-on training
MCQ:  Multiple choice question
OSCE:  Objective structured clinical examination
PTX:  Pneumothorax
PLE:  Pleural effusion
THOLUUSE:  Thorax, trachea, and lung ultrasonography in emergency and critical care medicine.

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References


Review Article

What is New and Innovative in Emergency Neurosurgery? Emerging Diagnostic Technologies Provide Better Care and Influence Outcome: A Specialist Review

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The development of emergency medical services and especially neurosurgical emergencies during recent decades has necessitated the development of novel tools. Although the gadgets that the neurosurgeon uses today in emergencies give him important help in diagnosis and treatment, we still need new technology, which has rapidly developed. This review presents the latest diagnostic tools, which offer precious help in everyday emergency neurosurgery practice. New ultrasound devices make the diagnosis of haematoma easier. In stroke, the introduction of noninvasive new gadgets aims to provide better treatment to the patient. Finally, the entire development of computed tomography and progress in radiology have resulted in innovative CT scans and angiographic devices that advance the diagnosis, treatment, and outcome of the patient. The pressure on physicians to be quick and effective and to avoid any misjudgement of the patient has been transferred to the technology, with the emphasis on developing new systems that will provide our patients with a better outcome and quality of life.

1. Introduction

When an emergency care system matures, the scope of emergency medicine (EM) expands. Most emergency department care is provided by specially trained physicians. There is a mature academic professional organization that can advance the field, which can now sustain fellowships and subspecialization, national databases, and peer reviewed journals. Emergency medical services systems are developed and run on city, regional, and even national levels. Internationally, two different systems have been developed for the delivery of emergency medical care. The first is the Anglo-American model that is familiar within the United States and the other is the Franco-German model. The Anglo-American model provides prehospital care. Paramedic and emergency medical technicians extend the role of the physician, caring for, stabilizing, and transporting the patient. On the other hand, in the Franco-German model, care is brought to the patient. Emergency systems used to provide out-of-hospital urgent care and to screen the patients to decide who needs to be transferred. The physician and the technology are sent to the scene in the hope of providing an immediate high level of care when most needed. Management systems are currently in place for process improvement, quality assurance, and cost controls. Countries that can be described as having mature emergency care systems include Australia, Canada, the United Kingdom, Germany, Switzerland, and the United States [1].

2. The Necessity of New Technology: Telemedicine

Rapid assessment of injuries and life-preserving therapy is required, but defining the optimal strategy can be complicated when multiple organ systems are involved [2]. The improvements needed in emergency neurosurgery can be supported by introducing new tools for specialists.

Although the gadgets and tools that the neurosurgeon uses today in emergencies give him important help in
diagnosing and treating the patient, we still need new technology. This should accelerate diagnosis and treatment. Moreover, it must be user-friendly, so that it can be used even by a junior physician and still give excellent results. Furthermore, modern technology concentrates on avoiding misdiagnosis, as this can lead to disastrous results for the patient. Additionally, rapid and specific diagnosis can always help to improve the patient’s quality of life.

Another very important instrument that has to be developed for neurosurgical emergencies is the telemedical emergency neurosurgical network. Teleeducation, teleconferencing, and teleconsultation have flourished, albeit mainly as a showcase between a number of emergency units within leading institutes [3, 4].

With advances in information and imaging technology, the application of robotic systems to the health sector has become a burgeoning field in assisting surgeons in manipulating, monitoring, and/or guiding operations, with the advantages of high targeting precision, reliable support during protracted operations, and the possibility of preoperative planning based on patients’ images. In 2001, around 270,000 image-guided robotic operations were conducted annually worldwide [3, 4].

In the developing countries, telemedicine holds promises increasingly balanced access to health care services. To this end, collaboration with the developed countries will increase and will help to ensure that expertise, knowledge, and experience are more rapidly and more cheaply available [3].

3. Novel Neurosurgical Tools

There have recently been rapid developments in medical technology in emergency departments. The present paper presents a spectrum of neurosurgical tools that have been developed in the last two years.

Researchers at UC Berkeley have been working on developing a new brain injury detector that is cheap, easy to use, and can provide nearly immediate results. This device sends radio signals that pass through the brain and are detected using a special antenna. The underlying technology is known as “Volumetric Electromagnetic Phase Shift Spectroscopy (VEPS)” and can detect changes in tissue properties inside the body through noncontacting, multifrequency electromagnetic measurements from the exterior of the body, thus providing rapid and inexpensive diagnostic testing (Figure 1) [5, 6]. This is a diagnostic method for brain injury that can be used in poor rural areas where the population has no access to advanced medical technology and services [5]. Thus, the patient will receive a rapid diagnosis, even from nonspecialized personnel, and it can then be decided whether to transfer him to advanced medical services for further neuromonitoring, which can be crucial for the outcome and the quality of life of the patient. Only time will tell which of these technological solutions will become commonly used in the future to help diagnose brain trauma, and the VEPS headset is only completing small trials at the moment, so it is still far from reaching the rural communities it hopes to help. Still, the innovation in this field shows that we may have improved treatments and diagnosis for traumatic brain injury not only rapidly but also well ahead of time [7, 8].

The updated infrascan model 2000 intracranial haematoma detector is another tool for the neurosurgeon that has received FDA approval (Figure 2). This is a device for detecting intracranial haematomas. It is meant to be a simple, easy-to-use screening tool, which can be used to identify high risk patients requiring further workup, including CT [9]. An estimated, 1.5 million individuals seek medical treatment for head trauma in the USA each year, and a total of 10 million individuals seek head trauma treatment annually worldwide [10–15]. Intracranial haematomas resulting from a traumatic brain injury are life-threatening and have been reported to
occur as the primary injury in 40% of patients with severe head injury [10–15]. Successful treatment often relies upon timely diagnosis and intervention prior to neurological deterioration. The early identification of a brain haematoma can play a significant role in facilitating transportation of critically injured patients to facilities which can verify Infrascanner’s early diagnosis and offer surgical intervention.

“Before the Infrascanner, first responders had to rely on imprecise methods to detect brain bleeds in patients, potentially delaying treatment,” said Dr. Joseph Maroon, Professor and Vice Chairman of the Department of Neurological Surgery at the University of Pittsburgh, team neurosurgeon for the Pittsburgh Steelers, and Medical Advisory Board member of civilian Infrascanner distributor, MedLogic, LLC. “Whether on the field of battle with military medical personnel or on the thousands of playing fields with sports health professionals in professional, amateur, or youth sports, the Infrascanner can potentially save lives by quickly detecting life-threatening brain bleeds earlier,” added Dr. Maroon. It seems to be the frontier for the further management of a potential patient with haematoma. This instrument can be easily used by any physician and can immediately demonstrate whether a haematoma is present or not. The first physician at the scene of injury can then decide whether the patient should be immediately transferred to an advanced medical centre to be treated and monitored. There is always the possibility of false positive results, which can be considered as minor faults, since the haematoma patients will be diagnosed immediately and the acute transfer to a neurosurgical department would be beneficial for the patient. This device uses near-infrared technology to detect intracranial bleeding. Extravascular blood absorbs near-infrared light more than intravascular blood, due to the higher concentrations of haemoglobin in an acute haematoma compared to brain tissue. The scanner measures the difference in near-infrared absorption and provides a simple signal that indicates whether bleeding is likely to be present [9, 16].

The Clotbust ER is another important ultrasound system that has received the CE mark and that is potentially an important tool for the emergency department (Figure 3). This is an ultrasound system from Cerevest Therapeutics, Inc., and is a sonolysis system used to treat ischaemic stroke in emergency settings. The Clotbust ER is designed to deliver therapeutic ultrasound energy noninvasively to occluded blood vessels in the brain, together with standard intravenous thrombolytic therapy. The energy of the ultrasound beam is transformed into energy of fluid motion. At very low pressures, this streaming inside the brain causes mild stirring, leading to the exposure of additional fibrin sites to plasmin. Integrated software controls the delivery of consistent therapeutic levels of energy required to attain acoustic streaming, which makes the device operator-independent and it avoids the need for an experienced ultrasound specialist [17–19]. Some clinical studies have suggested that when ultrasound energy is applied during conventional intravenous tPA thrombolysis, the process of clot lysis is augmented, allowing more rapid resolution of blood flow to the ischaemic brain. This process is termed sonothrombolysis. The hope is that in the future, IV thrombolysis may be superseded by the use of cavitating microspheres in conjunction with sonothrombolysis, which may hopefully enhance clot dissolution further. The small size of these spheres (1.2 microns) allows them to penetrate and pass through the fibrin matrix of the blood clot [20, 21].

This seems to be an essential tool for the physician in the emergency department. With this tool, the physician (even when he is not a specialist) can noninvasively deliver ultrasound energy to a patient who has just been diagnosed with an ischaemic stroke in the ER. The thrombus starts to dissolve and can be then treated with a standard intravenous thrombolytic agent. That is extremely important, since this can provide a better outcome and better quality of life for the patient with ischemic stroke, without the need for specialised personnel.

For stroke treatment and monitoring in the emergency department, attention must be drawn to the new device called Fore-sight from Casmed of Branford, CT, USA (Figure 4) [22]. A clinical evaluation led by Dr. David MacLeod at Duke University Medical Center in Durham, NC, USA, examined the relationship of cerebral tissue oxygen saturation (SctO2) measured by fore-sight to longer term postoperative cognitive...
decline 6 weeks after surgery. New clinical study results show that casmed’s fore-sight technology provides superior accuracy and potential for improved outcomes. Decreased forebrain cerebral tissue oxygen saturation is associated with cognitive decline after cardiac surgery [22]. Subjects were given a battery of cognitive tests, both before and 6 weeks after surgery, for verbal memory and language comprehension, figure memory, attention and concentration, and psychomotor and processing speed. This observational study showed that decreased intraoperative SctO2 levels are potentially associated with decreased cerebral tissue oxygen saturation measured by cerebral oximetry [23]. This device measures blood oxygen in a similar manner to a finger clip pulse oximeter. Continuous near-infrared regional cerebral perfusion monitoring is provided in stroke patients. The sensors stick on like adhesive bandages above each of the patient’s eyebrows and emit near-infrared light that penetrates the scalp and underlying brain tissue [24]. As with Clotbust, this device is easily used by nonspecialist physicians. The application of a simple sensor sticker provides essential information for the management of a stroke patient.

Another tool of significant importance for the neurosurgeon specialist in emergencies is the Presto, which monitors cranial blood flow without a sonographer (Figure 5). This is a device that has received FDA clearance and it allows any clinician to perform cranial blood flow monitoring without a professional sonographer. The system features proprietary autolocating technology that allows users to easily locate and keep the ultrasound beam focused on the cerebral artery [25]. The Presto 1000 Flow Monitor will help with ICU and surgical patients, by detecting abnormal changes in cerebral blood flow and alerting the attending nurse, bringing further institutional resources to diagnose the cause. These flow anomalies may be indicators of severe conditions, such as vasospasm from aneurysm ruptures or head trauma, disturbances in brain autoregulation or MCA blood clots [26]. Taking into account its function, and user-friendliness, this can be really considered as a vital device for neurosurgical emergencies. Without the specific knowledge of a sonographer, even a junior registrar can measure cranial blood flow and rather rapidly provide crucial information to the specialist. This ensures that appropriate treatment is rapidly provided and may even save the patient’s life.

An essential device for emergencies in neurological surgery is the HeadSense intracranial pressure monitor (Figure 6). In this device, the ear buds may help avoid having to drill into the skull. Elevated transcranial pressure from an injury or disease is a dangerous condition that can be life-threatening, painful, and debilitating. Because our thick skulls do not allow traditional external pressure monitoring, invasive methods that penetrate the skull have been used. This is why intracranial pressure monitoring continues to be rooted in the 20th century. With simple ear buds, even a nonspecialist junior physician can easily decide whether the patient’s intracranial pressure needs conservative or surgical treatment. This decision can be crucial for the patient’s life, as well as for economic health management. HeadSense, a company from Netanya, Israel, has been working on a noninvasive monitor that sends and detects sound waves to measure intracranial pressure. It looks like a generic mp3 player but, instead of playing music, the ear bud plays tones of different frequencies and measures how they sound from the other side of the head. A Bluetooth-enabled tablet receives the data from the HeadSense device and analyses it to provide a final output of the pressure [27].

Furthermore, the portable full body CT scanner—BodyTom—has been awarded the CE mark and is another important device for the emergency department (Figure 7). This is a battery powered tomograph and can be transported to the patient from room to room, allowing it to be used in places such as the clinic, the ICU, and the emergency department. The specifications of the scanner itself include a 32 slice CT with a 85 cm gantry and 60 cm view [28]. The BodyTom is the latest development in NeuroLogica’s portable computed tomography imaging line. The battery powered
BodyTom can be transported from room to room and is compatible with PACS, surgical navigation, electronic medical records, and planning systems. Its unique capabilities provide high quality CT images wherever needed, including the Clinic, ICU, operation room, and Emergency/Trauma Department. The combination of rapid scan time, flexible settings, and immediate image viewing makes the BodyTom a valuable tool to any facility needing versatile real-time CT imaging [29].

By providing real-time updates as the surgery unfolds, the scanner eliminates the need to move patients between operating room and radiology suite and makes surgery safer. BodyTom can obtain images of the entire spine in one pass, providing detailed three-dimensional images of both bone and soft tissue that is unavailable using the flat-panel fluoroscopic imaging that is typically found in most operating suites. This enables the surgeon to assess any developing complications before the patient leaves the operating room [30].

The importance of this device is (more than) obvious. You do not have to be a specialist to support its usefulness in emergencies. With this portable CT scanner, you can always have immediate neuromonitoring, even in the smallest medical centres. Moreover, the scanner is cost-effective, as it can be used by all the departments of the institute, especially if we are dealing with a small capacity medical centre.

Remaining with the theme of diagnostic testing and computed tomography monitoring, the IMRIS CT (Figure 8) should be mentioned. IMRIS Inc. (IMRIS) designs, manufactures, and markets the VISIUS Surgical Theatre, a multifunctional surgical environment that provides intraoperative vision to clinicians. Designed to fulfil a hospital’s clinical needs, the VISIUS Surgical Theatre can incorporate magnetic resonance (MR) imaging, computed tomography (CT) imaging, and X-ray angiography in a number of configurations, providing intraoperative images of diagnostic quality. IMRIS sells the VISIUS Surgical Theatres globally to hospitals that deliver clinical services to patients in the neurosurgical, cerebrovascular, and cardiovascular markets. The VISIUS Surgical Theatre incorporates magnetic resonance imaging, CT, and fluoroscopy into multipurpose surgical suites to provide truly intraoperative imaging for specific medical applications [31].

The FDA has given clearance to IMRIS for its ceiling-mounted intraoperative CT system, the VISIUS iCT. This is the world’s first and only such system that rides on a ceiling-mounted track and can be deployed around the patient within 30 seconds when necessary. Because the system does not touch the ground, there are many fewer things to keep in mind when deploying the scanner, and the operation can be resumed quickly once the scan is done [27]. It is obviously an extraordinary device. It saves time for the treatment of the neurosurgical patient in the operation theatre of the emergency department. However, this is an extremely specialist-oriented machine and its use can only be focused in special medical centres. It cannot be considered as the frontier tool for neurosurgical emergencies, but may be regarded as an essential device in reference neurosurgical centres. State-of-the-art CT imaging is then accessed effortlessly in the operation room (OR).

Developed for cranial and spinal neurosurgery, VISIUS iCT is a specialized multifunctional surgical theatre that brings state-of-the-art image quality directly to patients in the OR. The first and only ceiling-mounted intraoperative CT travels on-demand to the patient—without introducing additional risks by moving the patient or having anything touch the floor—and preserves the OR protocols, including optimal surgical access and techniques [32].

VISIUS iCT is a state-of-the-art surgical theatre that provides personalized dose management together with diagnostic quality imaging during the surgical procedure, in order to assist surgeons in critical decision-making. The 64-slice scanner effortlessly moves into and out of the operating room during surgery, using ceiling-mounted rails to ease workflow. This enables multiple room configurations to meet both clinical requirements and increased utilization without compromising image quality or exam speed.
Patient transport and the need for the floor-mounted rails used in other systems are eliminated, opening up valuable OR space and allowing unimpeded movement of surgical equipment and simplified infection control. The system also offers the longest scanner travel range on the market today.

In addition, VISIUS iCT features a suite of software applications, such as 3D volume rendering, in order to aid surgical planning and dose reduction. This considers each patient’s unique characteristics and needs to maximize image quality and minimize dose. “State-of-the-art dose management is one of the keys to driving the adoption of iCT to guide surgical procedures,” Graves said.

The system software allows healthcare practitioners to visualize dosage prior to scan and adjust settings based on the specific clinical need, with detailed dosage reports produced after each scan [33].

Finally, another new device that would be a great assistance to the specialist in the ED is the new angiography system from Siemens (Artis Q, Artis Q. zen), which has been awarded FDA approval (Figure 9). The device features the latest X-ray tubes and detectors, which together deliver the highest quality imaging and are capable of spotting tiny vessels in the brain and heart during interventional procedures. The system also features low radiation dose modes that allow imaging at lower quality when the best imaging is unnecessary [16]. This new angiography system though is also—as IMRIS CT—a device that cannot be used as frontline tool for neurosurgical emergencies. It must be used by specialists. Nevertheless, the features of the new angiography system make it an important implement for the structure of a developed neurosurgical centre, to improve the quality of patient treatment. The new imaging component techSiemens Artis Qnology is touted by Siemens as a “revolutionary new X-ray tube and detector technology” that will improve image quality and fine detail resolution, all with a dose level that is lower than the traditional tube and detector technology presently being used. The X-ray tube from Siemens now utilizes flat emitter technology rather than the traditional coiled filament technology. This is now coupled with the new detector design that utilizes crystalline silicon rather than amorphous silicon as the detector material. Siemens claims that the new design provides a more homogenous design with better signal amplification, while at the same time reducing the noise at ultralow dose settings. Thus, it provides better images at lower power and doses.

Siemens claims that the new combination of tube and detector provides visibility of small vessels at a rate that is 70% higher than with the previous generation technology. If this is proven to be clinically valid in everyday use, the promise of better resolution at lower power and lower dose levels will be a significant step, as interventional procedures become more and more complex with longer times. This may translate into the potential for extended exposure to radiation during the procedure [34].

In addition to the hardware innovations, there are several new software applications. The Artis Q and Q. zen will be the first angiography systems to feature IVUS map, integrating intravascular ultrasound (IVUS) with angiographic images. With the simultaneous views of the vessels’ interior wall via IVUS with precise location on the angioimage, IVUS map efficiently supports physicians in diagnostic testing and stent placement. CLEARstent Live enhances the visibility of stents in real time during therapy whilst simultaneously stabilising the image, resulting in a clear image of the intervention without time lag. Other new 3D applications, such as syngo DynaCT micro, provide substantial improvements in spatial resolution, by enhancing the smallest details in crucial areas such as imaging of intracranial stents or other miniscule structures, such as the cochlea in the inner ear. Organs such as the lungs can be imaged in 3D in less than three seconds with syngo DynaCT Highspeed, reducing the number of motion artefacts and the amount of contrast agent required. For oncological procedures, personalised therapy is the key to improve the access to the disease and to improve patient outcomes. A new 3D functional imaging protocol, syngo DynaPBV Body, shows blood distribution by means of colour coded cross-sectional blood volume maps, along with quantitative measurement of blood volume in lesions, in order to assess changes in perfusion over the course of treatment [35].

4. Ethics

The last twenty years have been the rise of neuroscience, molecular biology, and brain imaging technologies, which have changed our understanding of the human brain. Neuroscientists are currently working on the development of an array of therapeutic cognitive enhancements for humans. These technologies are in the pioneering stage and promise further insights into our understanding of the brain. Some scientists consider that the twenty first century will be to neuroscience as the twentieth century was to physics [36].

The sheer size of the brain’s neural network, comprising approximately 100 billion neurons and over 100 trillion synaptic connections, will represent an enormous challenge for NBIC in the future. Fantasies about mind control will remain elusive, since science has yet to determine how the brain encodes memory and more fundamentally how
mind works [37]. Developments in BMIs, for example, will probably comprise two phases; the current phase consists of therapeutically based BMIs for disabled persons and in the second phase, BMIs will be developed to enhance cognitive and motor skills in healthy humans [37]. McGee and Maguire (2001) also predict a third phase in BMI development, which will involve the use of neural devices for information transfer capability [38]. While this phase is still a long way off, it does indicate future possibilities for BMI once the technology is developed.

Episodes of neurosurgical care are associated with the expenditure of huge health system resources and have tremendous impact on quality of life and clinical outcomes, disproportionate to the size of our specialty and to the number of individual encounters. The complex medical, social, and ethical dimensions of these interventions preclude substituting mid-level providers, such as physician assistants and nurse practitioners, for the neurosurgeon. Many neurosurgical care episodes are concentrated at the extremes of age (i.e., at the beginning and end of life), focus on an uncompromising nervous system, and/or require continuous subspecialty coverage for stroke, hydrocephalus, and neurotrauma, and thus have tremendous impact on both healthcare and health system outcomes. For these reasons, neurosurgical practitioners have passionately embraced the modern era of medical education, training, and innovation as a method of improving the outcomes of our patients and for advancing our specialty. Neurosurgery has emerged as a leader and innovator, and is therefore an area of medical practice that should be targeted for additional support and enhanced attention to educational best practices, rather than cuts in economic support [39].

5. Discussion

ICT will no longer mean only intracranial tension. It will signify an even more important term—“Information and Communication Technology.” Distance today has become meaningless and geography has become history. Advances in medical technology and surgical techniques have dramatically improved diagnosis and treatment of most disorders, saving and extending lives. Yet the technology revolution has to bypass certain difficulties for urgent medical care in different hospital establishments. Tomorrow’s neurosurgeon will be part of digital health, digital hospitals, EMR, HIS, telemedicine, telemonitoring, and mHealth. With a mini iPad or equivalent low cost tablet, he/she will be able to work with anyone, anytime, anywhere. Professor Google and Dr. Facebook will ensure that the patient is truly empowered, with real time access to almost the same exabytes of information as the neurosurgeon. “Caveat emptor”—let the buyer beware—the neurosurgeon of 2020 could very well be on the receiving end [40]. Ultimately, aligning preclinical and clinical standards on a large scale, as well as the vast use of modern technology healthcare tools in emergency neurosurgery, has the potential to greatly impact the lives of patients waiting for new treatments for brain and spinal cord injury in A & E Departments worldwide. In the 50 years since computed tomography was introduced to everyday medical use, the importance of new diagnostic technologies has become increasingly crucial. The pressure on physicians to be quick, effective, and to avoid any misjudgement of the patient has been transferred to our technology. Neurosurgery is obviously faced with many new opportunities and challenges, based on advanced technological approaches and molecular approaches to neurosurgical problems. Advances in technology have allowed the neurosurgeon to precisely locate abnormal tissue in the brain and spinal cord, thereby preserving normal tissues from surgical trauma. However, it is far from easy to predict the future role of the neurosurgeon. It is doubtful whether important turns and unexpected novelties can be foreseen by people of today, who are anchored to the palpable realities and submitted to all kinds of current limitations. Exposure to fantasies and wishful thinking will easily lead to errors and misunderstandings. Prophecies of this kind will be impregnated by current limitations. The reality is that a neurosurgeon will continually feel the force of the development and the need for new technology that will provide our patients with better outcomes and quality of life.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References


Research Article

Assessment of a New E-Learning System on Thorax, Trachea, and Lung Ultrasound

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Background. Lung ultrasound has become an emerging tool in acute and critical care medicine. Combined theoretical and hands-on training has been required to teach ultrasound diagnostics. Current computer technology allows for display, explanation, and animation of information in a remote-learning environment. Objective. Development and assessment of an e-learning program for lung ultrasound. Methods. An interactive online tutorial was created. A prospective learning success study was conducted with medical students using a multiple-choice test (Trial A). This e-learning program was used as preparation for a certified course followed by an evaluation of trained doctors (Trial B) by linear analogue scales. Pretests were compared with postcourse tests and sustainability tests as well as a posttest of a one-day custom classroom training. Results. In Trial A, during the learning success study (n = 29), the increase of correct answers was 11.7 to 17/20 in the post-test and to 16.6/20 in the sustainability test (relative change 45.1%, P < 0.0001). E-learning almost equalled scores of classroom-based training regarding gain and retention of factual knowledge. In Trial B, nineteen participating doctors found a 79.5% increase of knowledge (median, 95% CI: 69%; 88%). Conclusion. The basics of lung ultrasound can be taught in a highly effective manner using e-learning.

1. Introduction

The increasing demand for ultrasound applications in critical care medicine requires a discerning analysis of current and emerging training methods. In particular, ultrasound diagnostics of thorax, trachea, and lungs remain underutilized, although it has been shown to deliver more specific and sensitive results than chest X-ray, for example in cases of pulmonary edema regarding B-line differential diagnostics [1], pneumothorax [2–4], or pulmonary consolidation [5–8].

The safety and accuracy of ultrasound-guided interventions have similarly been demonstrated in critical care scenarios such as thoracocentesis [9, 10]. Pulmonary ultrasound is considered of utmost importance in critical care ultrasound curricula [11, 12] and encompasses the impartment of cognitive and psychomotor skills for accurate interpretation and acquisition of sonographic images.

Lecture- and seminar-based events, the current standards for ultrasound training, are often inaccessible due to time or financial constraints, posing a substantial hurdle to interested
parties from medical students to board-certified doctors. While practical ultrasound skills may be quickly acquired in brief training courses [13, 14], the advancement of computer- and online-based training calls into question the necessity of a training seminar to convey pure theoretical knowledge of basic ultrasound concepts [15].

An online e-learning program can reduce the time, staff, and financial commitments of lecture-based training and promote active user involvement with the course material. The broad scope of e-learning and its accessibility enables knowledge to be conveyed quickly and effectively, ensuring its place in current and future learning applications [16]. Previous studies examining the effectiveness of e-learning programs in ultrasound training [17, 18] have primarily concentrated on using Internet media to present classical frontal lectures or enable a platform for tutoring, thereby removing the spatial drawback of attendance-based courses but retaining the typical teacher-student configuration. “Activation” of a learner is considered to be much more effective than passive listening to classical lectures [19].

We developed an interactive online training program as part of a critical care ultrasound training and aimed to analyze the success of independent theoretical skill development through an individual e-learning course as compared to a day-long training seminar with personal attendance provided by http://www.SonoABCD.de. http://www.SonoABCD.de is a network of multiple participating hospitals and institutions providing ultrasound education in Germany [13, 14, 20].

Our study was designed to determine the effectiveness and sustainability of content conveyed through the e-learning training program, as assessed by medical doctors and medical students. Further we compared factual knowledge gain with a generic attendance training.

2. Methods

2.1. Contents of the E-Learning System. The tutorial explains the basics of sonography and the most important physiological and pathological sonographic patterns of lung and pleura as defined by the International Consensus Conference on Lung Ultrasound [8]. Target groups were medical doctors and medical students. The module content is structured in 5 chapters: basics and pleural effusion, pneumothorax, pulmonary edema and consolidations, trachea, and workflow of a protocol-based lung ultrasound exam with exercises. Those 5 chapters contain a total of 21 units, which represent one screen each (Table 1).

2.2. Didactic Concept and Script. The theoretical approach was based on constructivism, which emphasizes a setting in which the learner arrives at his/her own conclusions and the “teacher” plays a more passive role in comparison to a classic frontal-lecture environment [21]. The script consists of 21 screens: one screen for each unit of the online tutorial. An important part in the learning process is interaction, whereupon the newly acquired knowledge is actively applied [22]. The units consist of ultrasound, X-ray and anatomical pictures, learning texts with key facts, and corresponding exercises: drag and drop, multiple choice, radio button, and fill-in-the-blank. An overview of the video clips and still images, including their respective sources, is provided (Table 1).

2.3. Production of the Online Tutorial. The anatomical sketches were drawn in coloured pencil and converted to Joint Photographic Experts Group (JPEG) standard format. All ultrasound videos were converted from their various formats to a flash-specific format using the Adobe Flash CS3 Video Encoder (Adobe Systems Inc., San Jose, CA, USA). The videos were cut in width and height as well as in duration to anonymize content as necessary and run in endless loops to facilitate uninterrupted viewing. Adobe Flash CS3 Version 9.0 was used as the main development tool, as its player plug-in allows presentation of videos and animations over the Internet in over 99% of browser programs installed in North America and Europe [23]. Each unit was saved as a source file (.fla), allowing later changes to be made, as well as an object file (.swf) for online display. Several learning units contain animations in terms of moving lines and arrows to denote specific structures in the sonographic videos. These animations were constructed by adding a layer for each object on the timeline on top of the videos, which creates the appearance of being inside or reaching into the videos.

The Web Kit Freiburg [24] was used as a template for the flash files. The Web Kit Freiburg itself was created in Flash (Adobe Systems Inc., San Jose, CA, USA) and delivered the framework and empty exercises originally created from the WEBGEO [25], in which a large number of the geography college courses were implemented as online tutorials. The user of the online tutorial loads an HTML file, which subsequently refers to all flash files containing the units. The online tutorial was first created in German language and later translated into English. The project’s development, testing, and file sharing platform were hosted by the Basic Support for Cooperative Work (BSCW) Internet server of the Goethe-University of Frankfurt am Main, Germany [26].

2.4. Learning Success Study with Medical Students (Trial A). A learning success study was conducted only with medical students. The entire study was done over the Internet, enabling every student to work through the online tutorial and take the tests at his own pace without any custom or hands-on training during the trial period. The online tutorial leveraged the WebCT platform [27] which offers the possibility of online testing and to which all students of Frankfurt University have access. The learning success study was composed of 20 multiple-choice questions with 4 answers each, out of which exactly one was correct. This test was copied from a former learning success study about a one-day course program with a combination of lecture and hands-on training entitled “Thorax and Lung Ultrasound in Emergencies/THOLUUSE [13, 14].” The participants of the THOLUUSE study were used as a reference group for comparison. Students took the test three times as pre-test, posttest, and sustainability test, with varied question and answer sequences. The pretest was available for one week, after which the online tutorial became
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<td>Drawing of pleura, lung, recess, diaphragm, liver</td>
<td>M. Barth</td>
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<td>Orientation film</td>
<td>Sonographic film of pleura, lung, recess, diaphragm, liver</td>
<td>T. Hirche</td>
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<td>Artifact film</td>
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<td>3</td>
<td>Thorax photography</td>
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<td>X-ray of pleural effusion, right</td>
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<tr>
<td>9</td>
<td>Lung point in M-mode</td>
<td>Sonographic image of lung point in M-mode</td>
<td>[30]</td>
</tr>
<tr>
<td>9</td>
<td>Lung point schematic sketch</td>
<td>Schematic explanation of the lung point</td>
<td>[30]</td>
</tr>
<tr>
<td>10</td>
<td>Lung pulse in M-mode</td>
<td>Sonographic film of lung pulse in M-mode</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>10</td>
<td>Lung pulse in B-mode</td>
<td>Sonographic film of lung pulse in B-mode with Doppler</td>
<td>T. Hirche</td>
</tr>
<tr>
<td>11</td>
<td>Trachea anatomical sketch</td>
<td>Drawing of the trachea in transversal sectional image</td>
<td>M. Barth</td>
</tr>
<tr>
<td>11</td>
<td>Trachea longitudinal sonogram</td>
<td>Sonographic longitudinal image of the trachea</td>
<td>R. Breitkreutz</td>
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<tr>
<td>12</td>
<td>Neck anatomical sketch transversal</td>
<td>Drawing of transversal sectional image of the neck</td>
<td>M. Barth</td>
</tr>
<tr>
<td>12</td>
<td>Trachea transversal sonogram</td>
<td>Sonographic transversal image of the trachea</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>13</td>
<td>Pneumothorax split screen</td>
<td>Sonographic image of a pneumothorax in split screen B-mode and M-mode</td>
<td>[30]</td>
</tr>
<tr>
<td>13</td>
<td>Lung point split screen</td>
<td>Sonographic image of the lung point in split screen B-mode and M-mode</td>
<td>[30]</td>
</tr>
<tr>
<td>14</td>
<td>Lung split screen</td>
<td>Sonographic film of physiological lung in split screen B-mode and M-mode</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>15</td>
<td>Thorax with probe</td>
<td>Thorax with ultrasound probe and 6 sectors for examination</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>15</td>
<td>Lung 6 split screens</td>
<td>6 images in split screen B-mode and M-mode of different sectors of the thorax, one of which with pneumothorax</td>
<td>R. Breitkreutz</td>
</tr>
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</table>
### Table 1: Continued.

<table>
<thead>
<tr>
<th>No.</th>
<th>Image (Name)</th>
<th>Description</th>
<th>Source</th>
</tr>
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<tr>
<td>16</td>
<td>Trachea longitudinal for practice</td>
<td>Sonographic longitudinal image of the trachea</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>16</td>
<td>Trachea transversal for practice</td>
<td>Sonographic transversal image of the trachea</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>17</td>
<td>Pleural effusion film</td>
<td>Sonographic film of pleural effusion with atelectasis (as on screen No. 5)</td>
<td>T. Hirche</td>
</tr>
<tr>
<td>18</td>
<td>Alveolointerstitial syndrome</td>
<td>Sonographic film lung contusion, multiple B-lines</td>
<td>[29]</td>
</tr>
<tr>
<td>18</td>
<td>Lung consolidation</td>
<td>Sonographic film of consolidated lung parenchyma</td>
<td>R. Breitkreutz</td>
</tr>
<tr>
<td>18</td>
<td>peripheral parenchymal lesions</td>
<td>Sonographic image with multiple peripheral parenchymal lesions</td>
<td>[29]</td>
</tr>
<tr>
<td>18</td>
<td>peripheral parenchymal lesion</td>
<td>Sonographic image with multiple peripheral parenchymal lesion and B-line</td>
<td>[29]</td>
</tr>
<tr>
<td>19</td>
<td>Air bronchogram</td>
<td>Sonographic image of lunge with air bronchogram</td>
<td>[31]</td>
</tr>
<tr>
<td>20</td>
<td>Lung infarction</td>
<td>Sonographic image of lung infarction after pulmonary embolism</td>
<td>[31]</td>
</tr>
<tr>
<td>20</td>
<td>Triangular lung infarction</td>
<td>Sonographic image of triangular lung infarction after pulmonary embolism</td>
<td>[32]</td>
</tr>
<tr>
<td>20</td>
<td>Rounded lung infarction</td>
<td>Sonographic image of rounded lung infarction after pulmonary embolism</td>
<td>[32]</td>
</tr>
<tr>
<td>21</td>
<td>Pulmonary edema with 5 B-lines</td>
<td>Sonographic film of a pulmonary edema with 5 B-lines</td>
<td>[33]</td>
</tr>
<tr>
<td>21</td>
<td>Pulmonary edema with confluent B-lines</td>
<td>Sonographic film of a pulmonary edema with confluent B-lines</td>
<td>[34]</td>
</tr>
</tbody>
</table>

M. Barth, T. Hirche and R. Breitkreutz provided pictures from their private archives.

Available for two weeks. Following the tutorial, the posttest was administered within the 4th week, after which the online tutorial was no longer available for knowledge refreshment. After a two-week waiting period without access to the e-learning program, participants were allowed for one week at the seventh week of the study to take the sustainability test. At no time during the trial were the participants given access to the answer key. To augment participation compliance, ten monetary prizes between 20 and 50 Euros were distributed to the top scorers. According to the study design, only those students who participated in all three tests were incorporated into the final statistical consideration (Figure 1).

#### 2.5. Evaluation of the Online Tutorial by Medical Students.

The participants of the learning success study were subsequently asked to evaluate the online tutorial. This evaluation was carried out using the Internet tool survey monkey [35] and the questions were scaled discretely from 0 to 10 (Table 2). The participants were additionally asked about the time (in minutes) they spent working through the online tutorial.

#### 2.6. Evaluation of the Online Tutorial by Medical Doctors (Trial B).

Four weeks prior to the one-day training courses on thorax, trachea, and lung sonography, the online tutorial was provided to medical doctors as a preparation for the course [13]. The participants received logins and passwords for the BSCW server. After their training course, they were asked to evaluate the online tutorial using a 13-question linear analogue self-assessment (LASA) survey. Each question was displayed individually on an A4 landscape-format page accompanied by a single, horizontal, 20 cm line without numbers. Participants could mark the line in between two extremes (example question as warm up “How was the coffee today?” ranging from “very bad” to “very good”). The marks were measured to an accuracy of 1 mm and those measurements converted into percent values (Table 3). The participating medical doctors were also given the opportunity to make additional comments on the second page of the survey.

#### 2.7. Statistical Methods.

Data analysis and sample size planning were performed using BIAS 9.04 (BIAS, epsilon Verlag, Frankfurt, Germany). Wilcoxon matched pairs test was used for analysis of pre- and postintervention test results. A P value of less than 0.05 was considered to be significant, thus indicating group differences. Distributions of variables are indicated as mean, median, and 25th/75th percentiles and shown as box plots. We aimed for descriptive explorative data analysis only. Case number calculation by a biostatistician control centre (Dr. H. Ackermann, Institute for Biostatistics and Mathematical Modeling, Hospital of the University of Frankfurt, Frankfurt am Main, Germany).
3. Results

3.1. Expert Evaluation. Before the e-learning was used by our test group, an English version was evaluated by nine experts of the International Lung Ultrasound Consensus Conference [8]. This assured the quality of the tutorial prior to the start of testing and the conformity to consensus terminology. Thus, limitations in completeness and precision were improved, although not all of the 73 consensus statements were included as we did not want to integrate highly specialized lessons (e.g., ARDS) in the tutorial (Table 1). Remarkably, both main questions related to prelearning and use in their own training programmes were answered with a score of more than 90% (Figure 2).

3.2. Quantitative and Qualitative Evaluation by Students (Trial A)

3.2.1. Quantitative Evaluation. Of the 36 registered participants, 29 completed all three tests (81%), thus exceeding the required number \((n = 15)\) determined by the study design. The participating students scored significantly higher in the posttest and sustainability test than they did in the pretest (Figure 3).

3.2.2. Pretest versus Posttest. The mean score on the pretest was 11.7 (median 12, 25%; 75% percentile 9.5; 13.5,) while the mean of the posttest was 17.0 (median 17, 25%; 75%
Table 3: Questions of qualitative evaluation survey of the e-learning program using linear analogue self-assessment by medical doctors.

(1) How do you evaluate the subject matter?
(2) How well were the modules defined?
(3) Were enough details presented?
(4) Could you recognize the structures on the ultrasound clips?
(5) Was a central theme apparent throughout the modules?
(6) How significant was your knowledge gain?
(7) Was the time requirement acceptable?
(8) How well prepared do you feel for the practical course?
(9) How much time were you able to invest in the e-learning course?
(10) How many units did you complete?
(11) How well were you able to operate the e-learning program?
(12) How solvable were the tasks in the e-Learning program?
(13) How high was your motivation level for e-Learning?

percentile 16; 19), equalling a relative improvement of 45.1% ($P < 0.0001$ in Wilcoxon’s matched pairs test). Individually, 26 of 29 students displayed an improvement in score, two had a decline (which were also the worst scores in the posttest overall), and one had no change in score. Nearly half (14/29) of all participants achieved a score of 18/20 or higher (90%), suggesting a very positive learning effect (Figure 3).

3.2.3. Pretest versus Sustainability Test. Similarly to that of the posttest, the sustainability test mean of 16.6 (median 17, 25%; 75% percentile 15; 18) was significantly higher than that of the pretest mean of 11.7 (median 12, 25%; 75% percentile 9.5; 13.5), displaying a relative improvement of 41.8% ($P < 0.0001$ in Wilcoxon’s matched pairs test). Only one of the 29 participants had a lower score in the sustainability test as compared to the pretest (Figure 3).

3.2.4. Posttest versus Sustainability Test. In comparison to the pre-test, both the posttest and sustainability test showed significant improvement. The results of the posttest 17 (median 17, 25%; 75% percentile 16; 19) and sustainability test 16.6 mean (median 17, 25%; 75% percentile 15; 18) did not differ significantly from each other ($P = 0.237$), suggesting a positive long-term learning effect amongst the participants of the e-learning lung ultrasound program (Figure 3).

3.2.5. Comparison of E-Learning with THOLUUSE. Although the theoretical knowledge and learning success test were identical to that of the parent study, THOLUUSE [13] in which both theoretical and practical knowledge were conveyed in a day-long, attendance-based thorax and lung ultrasound course, it is important to acknowledge that the e-learning program is not able to incorporate the practical knowledge transfer that imparts the critical psychomotor skills required for ultrasound application. In addition to the identical multiple-choice test used, the results were also very similar in both studies. In both courses, the mean and median values of the pretest (e-learning mean: 11.7, median: 12, 25%; 75% percentile: 9.5; 13.5, THOLUUSE mean: 11.5, median: 12, 25%; 75% percentile: 10; 13) as well as the posttest (e-learning mean: 17, median: 17, 25%; 75% percentile: 16; 19, THOLUUSE mean: 16.8, median: 17, 25%; 75% percentile 16; 18) and sustainability test (e-learning median 17, 25%; 75% percentile 15; 18) were identical. The average relative
improvement in both tests was also very similar (45.1% and 41.81% e-learning, 45.71% THOLUUSE) (Figure 3).

3.2.6. Qualitative Evaluation of Medical Students. Of the 34 students who were asked to do so, 19 returned both a completed evaluation of the program and all tests they had participated in. In addition to 6 questions assessing the effectiveness of the program (Table 2), the students were also asked to estimate the time they took to complete the units. This question was answered by 14 of the 19 students and indicated that most \( n = 8 \) users completed the program within a 40 to 60 minute time frame, corresponding to approximately 2-3 minutes per unit. Two students completed all units within 15–20 minutes, averaging less than 1 minute per unit, and three students took between 6 and 8 minutes per unit (Figure 4). With the clear exception of question 2, the responses were overwhelmingly positive (Figure 4). The study organization was rated highest amongst the students (mean 90, median 100, 25%; 75% percentile 90; 100). The lowest rating, prior knowledge (mean: 20, median: 20, 25%; 75% percentile 10; 40), indicates that the majority of participants in the student-based study had no previous exposure to sonography. The rather high ratings of question 3 (mean: 80, median: 80, 25%; 75% percentile 70; 100) likely reflect the fact that many medical students in Frankfurt are familiar with the WebCT program and therefore had few or no problems operating it. The students rated their individual motivation predominantly positively (mean: 70, median: 80, 25%; 75% percentile 70; 100), corresponding to the positive self-assessment of motivation in the qualitative post-training survey of medical doctors. The e-learning program itself was rated second highest (mean: 80, median: 80, 25%; 75% percentile 80; 100), which likely indicates that many students have been exposed to similar pathways of online study and could use these for comparison. Personal assessment of individual learning success was also rated positively (mean: 80, median: 80, 25%; 75% percentile 70; 90), similar to the feedback of the identical question posed to the medical doctors (Figure 5).

3.3. Qualitative Evaluation by Medical Doctors (Trial B). 13 of the 34 completed surveys answered the question, "how long did the e-learning program take you in minutes?" Nine participants required between 30 and 50 minutes to complete the e-learning modules, two took more than 50 minutes, and two fewer than 30. Eleven doctors indicated that they had completed all answers in this reported time (Figure 5).

A total of 34 of 50 distributed surveys were returned with completed evaluations of the 13 questions using LASA.

The medians of each of the 13 questions surpassed 70. The response to question 10, "how significant was your knowledge gain?" (mean: 91, median: 100, 25%; 75% percentile 95; 100) was particularly positive (Figure 5).

The 13 individual questions were grouped into four categories: individual effort (Questions 9, 10, and 13), content evaluation (1, 3, 5, 12), practical application (2, 4, 7, 11), and success (6, 8) (Figure 5).
The category for individual effort received the highest ratings (mean: 79, median: 84, 25%; 75% percentile 72; 100), reflecting the fact that most of the doctors completed the entire program. Ratings were similarly high in the objective evaluations of program content (mean: 75, median: 79, 25%; 75% percentile 66; 87) and user-friendliness (mean: 77, median: 82, 25%; 75% percentile 67; 90) as well as in the subjective assessment of personal learning success (mean: 74, median: 79, 25%; 75% percentile 64; 87) (Figure 5).

The participating medical doctors were given the opportunity to make additional comments on the second page of the survey. Four doctors wrote that they were unable to complete the survey due to time constraints; another reported an unspecified error message, which prevented him from completing the program. Three participants in the first course commented that a user guide for the e-learning program would have been helpful; this was then assembled and distributed in the second course. Several positive comments were received from the participants regarding course and program organisation.

4. Discussion

Ultrasound is regarded to be a crucial diagnostic tool in many clinical questions of critical care medicine [36]. It is therefore imperative that ultrasound training is concisely and effectively conveyed to course participants. Appropriate application of ultrasound requires the ability to cognitively recognize and interpret pathological images as well as acquire the images using an ultrasonic device and psychomotor skills, the latter of which must be taught through practical hands-on training. Image recognition and theoretical basics, however, were demonstrated by our study to be effectively conveyed by an online e-learning program which requires neither the financial nor the time commitment that an attendance-based training demands.

The knowledge gain in image recognition and basic sonographic theory is nearly identical to that of its parent study THOLUUSE [13, 14] which was able to demonstrate the effectiveness of a one-day classroom-based training (for thorax, trachea, and lung ultrasound). This strongly suggests that the theoretical portion of such a course could be completed at the participant’s convenience previous to the practical, hands-on teaching.

In the evaluations received from the medical doctors, the median values of each of the 13 questions surpassed the score of 70%, enabling the conclusion that most participants were generally satisfied with the organization and content of the e-learning program.

The often-proven advantage of interactive learning in comparison to a lecture-based setting [37–39] is an additional argument for the application of e-learning programs to convey theoretical knowledge. Many previous e-learning studies have confined themselves to classical frontal lecture or student-teacher compositions [17, 18], thereby wasting the opportunity to exploit the advantage of an interactive learning system. The single study utilizing interactive e-learning in ultrasound [40] concerns procedural skills as opposed to the sonoanatomical knowledge the current study conveys. As critical as the psychomotor component of image acquisition is, it is mandatory to acquire the cognitive ability to recognize normal and pathological findings within the images [41]. The necessary interaction required by our e-learning program yielded the positive results that prove that the learned theoretical material is stored beyond the short-term memory of the participant, providing a solid base on which the practical skills of ultrasound diagnostics can be built.

Critics of e-learning question the effectiveness of such a program, which depends heavily not only on the competence of the learner, but also on his or her motivation to set learning goals and realize the steps to achieve them [42]. While motivation did not seem to be a hindrance within the boundaries of our study, further studies need to be carried out to compare actual (as opposed to self-estimated) performance on the practical portion of the training. A possible way to achieve this would be to merge the current study with the THOLUUSE study as a blended learning concept: offering the theoretical portion as e-learning and comparing the results of the subsequent practical training with that of THOLUUSE and as a future expanded concept adding further trainee-centred tools such as work books, quizzes, training in scenarios, and postcourse trainer/trainee interaction.

5. Limitations

Study limitations include the inability to randomize the study and the fact that participants were aware in advance of the intention and basic content of the e-learning program. Furthermore, participants were volunteers, which may have skewed motivation-related results in a more positive direction than if the modules had been completed by all students of a particular semester, for example. Several students seemed to speed through the e-learning program at an average rate of 1 minute per module, thus suggesting an overly rash preoccupation with their contents. The high mean scores of the posttest and sustainability test dispute this: despite the relatively quick processing of new knowledge, these inexperienced sonographers were able to apply their skills appropriately and effectively. Another limiting factor is that no sustainability test was performed by the medical doctors. A subsequent study would have to analyze both e-learning and classroom-based learning in a randomized fashion with both pretests and sustainability tests.

6. Conclusions

E-learning has great potential to provide a substantial theoretical basis of sonoanatomical principles and image recognition, the results of which are comparable to attendance-based courses. We recommend the use of e-learning to provide this knowledge to the widest audience possible, ensuring long-term retention of learned tenets and provoking interest in further practical training. E-learning is set to become
a vital part of theoretical training in lung ultrasound and may induce future trainee-centred blended learning programs.

Acknowledgment

The authors want to thank Dr. H. Ackermann (Institute for Biostatistics and Mathematical Modeling, Hospital of the University of Frankfurt, Frankfurt am Main, Germany) for his help with the power calculation.

References


Research Article

Assessment of a Low-Cost Ultrasound Pericardiocentesis Model

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Introduction. The use of ultrasound during resuscitation is emphasized in the latest European resuscitation council guidelines of 2013 to identify treatable conditions such as pericardial tamponade. The recommended standard treatment of tamponade in various guidelines is pericardiocentesis. As ultrasound guidance lowers the complication rates and increases the patient’s safety, pericardiocentesis should be performed under ultrasound guidance. Acute care physicians actually need to train emergency pericardiocentesis.

Methods. We describe in detail a pericardiocentesis ultrasound model, using materials at a cost of about 60 euros. During training courses of focused echocardiography \( n = 67 \), participants tested the phantom and completed a 16-item questionnaire, assessing the model using a visual analogue scale (VAS).

Results. Eleven of fourteen questions were answered with a mean VAS score higher than 60% and thus regarded as showing the strengths of the model. Unrealistically outer appearance and heart shape were rated as weakness of the model. A total mean VAS score of all questions of 63% showed that participants gained confidence for further interventions.

Conclusions. Our low-cost pericardiocentesis model, which can be easily constructed, may serve as an effective training tool of ultrasound-guided pericardiocentesis for acute and critical care physicians.

1. Introduction

Pericardial tamponade is a potentially life-threatening condition and can lead to cardiac arrest. The latest ERC guidelines of 2010 emphasize the use of ultrasound during resuscitation in order to detect reversible causes such as pericardial tamponade to provide early and targeted treatment [1]. It has been shown that echocardiography can be integrated into peri-resuscitation care in an ALS-conform fashion [2]. Thus, acute care physicians will encounter patient scenarios where no specialist is available, but a treatable condition needing immediate intervention is detected. There are several conflicts. Ultrasound now can detect reversible conditions such as tamponade. Thus, emergency or critical care physicians face the problem for treating these conditions, even without experience due to a lack of training in ultrasound-guided pericardiocentesis, because training phantoms are not readily available. Also, the required equipment needed to perform pericardiocentesis is not available in all ambulances or emergency rooms.

The skill for performing a focused echocardiography exam can be acquired in brief training courses [3]. The recommended standard treatment of tamponade in various guidelines is pericardiocentesis. It has been shown that pericardiocentesis can safely be performed under echocardiographic guidance with success rates as high as 100% [4–6]. Most physicians as well as specialists have not been trained to perform pericardiocentesis during their residency and do not feel comfortable while performing it. Several ultrasound
models or phantoms for teaching and training ultrasound-guided procedures, such as venous puncture, have been developed [7, 8]. For the training of pericardiocentesis, both the cadavers and pericardiocentesis training models are available [9]. These models have been shown to facilitate practicing the skills needed to perform pericardiocentesis.

However, most of the available models are expensive (i.e., the “Blue phantom” trans thorasic echocardiography and pericardiocentesis ultrasound training model starting at 15,000 USD [10]) and cannot be afforded by many institutions, especially in low-income countries. A low-cost pericardiocentesis phantom has been published during our project timeline, but there was no systematic evaluation of its features and its effectiveness [11].

We aimed to (1) construct a low-cost pericardiocentesis phantom that can be rebuilt easily and to (2) assess its effectiveness.

2. Methods

2.1. The Design of the Pericardiocentesis Model. A square plastic container was constructed using PVC-planks (22 × 22 × 14 cm, thickness 0.3 cm), filled with gel wax, which was heated until liquid (about 80–100°C), and then filled into the container (Figure 1). The gel wax served as a stable platform within the phantom. For the heart model, a celluloid table tennis ball was filled with water using a syringe until no air was left inside. This water-filled celluloid ball was to mimic a ventricle. The ball was then put into a balloon, which was filled with red ink-colored water until it was deaerated completely and knotted. This balloon was placed onto the solidified gel wax. The container was then filled with ultrasound gel to the brim, and all the air bubbles inside the ultrasound gel were smoothed out using a spoon or a syringe (Figures 1(a)–1(h)). Finally, the model was covered by silicone skin or Thera-Band, a rubber band usually used for gymnastic exercises (Figures 2(a) and 2(b)). These were to mimic the skin piercing. All materials needed for the construction of the model cost approximately 60 euros in total, and the preparation can be completed within 2 hours. The specific materials we used and their prices in common stores are listed in Table 1. Instead of the plastic container used in our model, any square container withstand heating can be used; the most expensive part of the model was the gel wax which also can be replaced by gelatine to reduce further costs.

2.2. Ultrasound Equipment and Ultrasound-Guided Pericardiocentesis. We used a mobile ultrasound device (Vscan, GE healthcare) for the purpose of the study. Study participants were asked to place the probe onto the model, simulating both the parasternal long- and short-axis views. Structures identified on the ultrasound image were skin, surrounding tissue, pericardium, pericardial effusion, and the heart model (left ventricle) (Figures 3(b)–3(d)). For cannulation, an 18 G needle with a 5 or 10 mL syringe attached was used. The needle was visualized during the entire procedure and advanced until seen inside the pericardium (Figure 3(d)). A reddish fluid could be aspirated if the needle was correctly placed inside the pericardium. After the tap, a decrease in the pericardial effusion volume could be seen (Figures 4(a) and 4(b)).

2.3. The Study Participants. The study participants were recruited during focused echocardiography in life support training courses (FEEL) organized by http://www.sono-abcd.org/. These courses, opened to physicians of all specialties, are part of a postgraduate training programme in the emergency ultrasound of Germany, Austria, and Switzerland and were certified by the German Society of Ultrasound in Medicine (DEGUM).

As a control group, medical students without prior exposure to ultrasound or pericardiocentesis were recruited for the study. All subjects participated voluntarily and granted verbal consent to allow collecting the data anonymously and to be processed and published. This trial is a part of a series of studies in emergency ultrasound from our working group and approved by the institutional review board, as stated in previous reports [2].

Participants were asked to fill out a 16-item questionnaire with a visual analogue scale (VAS) directly after using the pericardiocentesis model. Each question was accompanied by a single, horizontal 16 cm line without numbers. Participants could mark the line in between two extremes (example question: “How well can the heart be recognized in the phantom?” ranging from “very bad” to “very good”). The marks were measured to an accuracy of 1 mm, and those measurements were converted into percent values (Table 2). The questions were related to visualization of heart, pericardium and effusion, visualization of the needle, sense of puncture through the pericardium, how close they felt the model came to reality, and if they felt that the model increased their self-assurance in regard to ultrasound-guided pericardiocentesis (Table 2).

Table 1: List of materials used in our model. Instead of gel wax, gelatine can be used to reduce costs. Any kind of plastic container with a square form is suitable as well.

<table>
<thead>
<tr>
<th>Material</th>
<th>Retailer (for our model)</th>
<th>Cost (euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container made of PVC-planks, thickness 0.3 mm</td>
<td>Modulor, 10969 Berlin, Art.Nr: 132930</td>
<td>9.50</td>
</tr>
<tr>
<td>Gel wax</td>
<td>Mixed Store, 74532 Ilshofen</td>
<td>23.99</td>
</tr>
<tr>
<td>Gel (4 l)</td>
<td>Sonosi I L, Asid Bonz GmbH, 71083 Herrenberg, PZN 5362311</td>
<td>3.55 (x4)</td>
</tr>
<tr>
<td>Balloon about 30 cm</td>
<td>Basis Balloons, Luftballonwelt, 21436 Marschacht, Art.Nr: 90230</td>
<td>0.15</td>
</tr>
<tr>
<td>Celluloid ball</td>
<td>Elite I®, DONICS Schildkröt, D-82515 Wolfratshausen</td>
<td>0.49</td>
</tr>
<tr>
<td>Silicon skin/Thera-Band</td>
<td>Schmidt Sports PHYSIO TAPE, 42699 Solingen, Art.Nr. III1202</td>
<td>7.59</td>
</tr>
</tbody>
</table>
Additionally, participants were asked if they had performed any kind of puncture, no punctures before, or if they had distinct experience in pericardiocentesis. Question 16 asked all participants about their profession and their specialty.

Three groups of participants were defined according to the level of previous experience with pericardiocentesis or punctures. Group 1 consisted of participants who had no experience with punctures of any kind \( (n = 41) \). Group 2 was formed of participants who had not performed any pericardiocentesis before but had experience in performing other kinds of punctures (i.e., neuromuscular blocks and central lines) \( (n = 17) \). Group 3 consisted of participants who marked that they had performed pericardiocentesis before \( (n = 9) \).

Statistical analysis was performed using GraphPad Prism 5, La Jolla. Only descriptive statistics (mean, median, and standard deviation) were calculated. The scores of the three groups were compared using the Mann-Whitney \( U \) test in order to identify the differences in ratings between the groups.

A percentage value above 60% was defined to represent the strengths of the phantom and the value below 60% to represent the weaknesses. The liberal 60% cutoff value was chosen, as the model was not created to represent reality as best as possible but to simulate the act of puncture using a readily available phantom.

3. Results

The model was constructed several times by a fellow (AS) and was assembled in a mean time of about 2 hours. A single phantom was used for more than 60 punctures without being destroyed. The ultrasound appearance of the model after more than 60 punctures and 4 weeks of storage at room temperature is shown in Figure 4(c). Only the balloon with the enclosed celluloid ball had to be replaced so that
Figure 2: Two types of skin can be used: (a) silicone skin or (b) Thera-Band.

Figure 3: A participant is pericardiocentesis (a), the corresponding image is shown in (b), the left ventricle is colored in red, the effusion is colored in blue (c), and visualization of the needle is shown by yellow arrow (d).
the model could be used for further training. The first model was constructed in 2011 and showed no signs of moulding or decay even after more than 24 months of storage at room temperature.

A total of $n = 67$ participants (specialties: 40 anaesthesia, 13 internal medicine, 3 surgery, 4 students, and 7 physicians without specialisation) used the pericardiocentesis model and filled out a questionnaire during two ultrasound courses in April and June 2013. As specified above, three groups were defined according to the level of experience regarding pericardiocentesis. There was no statistically significant difference in the answer score to any of the 16 questions between the 3 groups. Therefore, data were pooled and presented as box plots (Figure 5). Mean scores for questions 1 to 14 ranged from 48% to 78%. The 60% cutoff value was surpassed in 11/14 questions. The weaknesses of the phantom were questions 9, 11, and 12, showing that the model was regarded as not realistic by most participants, and that the decrease in fluid could not be followed well. The highest scores (78% ± 19, mean ± SD, and 76% ± 18, resp.) were reached for questions regarding the visibility of the effusion and its discrimination from the surrounding tissues. Training with the phantom increased the confidence to perform future pericardiocentesis (63 ± 3).

4. Discussion

Pericardiocentesis as the standard treatment for pericardial effusion and tamponade has to be performed under great pressure in situations such as shock and resuscitations. In the era of interventional cardiology, the incidence of tamponade has increased and postcardiotomy effusions after hospital discharge can be observed [2, 6].

Echocardiographic guidance has increased the safety and lowered the complication rates [6]. The current ERC guidelines of 2010 enforce the use of ultrasound in peri-resuscitation settings to identify reversible causes such as pericardial tamponade [1].
Table 2: Questions of the evaluation of the phantom. All questions except no. 16 had to be answered via a visual analogue scale (VAS).

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of question</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Visualization of structures in short-axis</td>
<td>How well can a pericardium be recognized in the phantom?</td>
</tr>
<tr>
<td>2</td>
<td>How well can a heart be recognized in the phantom?</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Visualization of structures in long-axis</td>
<td>How well can a pericardium be recognized in the phantom?</td>
</tr>
<tr>
<td>4</td>
<td>How well can a heart be recognized in the phantom?</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Visibility and identification of a pericardial effusion</td>
<td>How well can free fluid be seen in the phantom?</td>
</tr>
<tr>
<td>6</td>
<td>How well can the fluid be distinguished from the surrounding tissue?</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ultrasound-guided puncture</td>
<td>How well is the puncture of the pericardium feasible?</td>
</tr>
<tr>
<td>8</td>
<td>How well is the needle tip visible?</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Aspiration of fluid from the pericardial space</td>
<td>How well is the decrease of fluid visible?</td>
</tr>
<tr>
<td>10</td>
<td>How well can a pigtail catheter be inserted?</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>General judgement of the phantom</td>
<td>Is the phantom realistic?</td>
</tr>
<tr>
<td>12</td>
<td>How well does the heart correspond to a real heart?</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Training on this phantom makes me more confident in ultrasound-guided pericardiocentesis.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>I am experienced in pericardiocentesis...</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>I have already accomplished pericardiocentesis...</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Profession</td>
<td></td>
</tr>
</tbody>
</table>

As most physicians do not practice pericardiocentesis in a controlled environment (i.e., cath lab or ICU) routinely, ultrasound phantoms have been designed as simulation has been shown to increase the competencies of physicians in medical procedures [12].

Available pericardiocentesis trainers are either expensive or nondurable when used multiple times [9, 10]. The goal of our study was to construct a pericardiocentesis phantom that is easily rebuilt, available to small institutions and low-income countries and can be reused multiple times.

The model we constructed costs about 60 euros and can be assembled using readily available materials in about 120 minutes. To reduce further costs, some of the materials can be replaced at an expense of reduced durability.

Zerth et al. published only recently another model but reported that the model can only be stored for 2 weeks at room temperature and used for about 40–50 punctures [11]. As we did use gel wax instead of gelatine, our model will not mould and can be stored for more than two years. Our models were used in average for more than 60 attempted punctures. After those 60 attempted punctures in a training course and 4 months of storage, only the balloon surrounding the celluloid ball had to be replaced as all surrounding structures were still intact (Figure 4(c)). This can easily be done by lifting the silicone skin, replacing the balloon, smoothing out air bubbles, and covering the model with the artificial skin again. Thus, it can be reused with minimum repair effort in discontinuous teaching pathways.

Replacing the gel wax with gelatine may also reduce costs but also will make the model prone to moulding. As a less expensive substitute for the PVC-planks, we used to assemble a square container; any plastic container available in the required format can be utilized (i.e., 2.5 Liters by http://www.becherprofi.at/, product ID 00200835 for 0.81 euro a piece). All of the required materials are readily available, and the construction of the model is independent of specialized tools. As the durability of the presented model in regard to its low cost is high, our development may be used as an alternative to high end simulation equipment. Especially in resource-limited settings, low-cost models are needed for sufficient training. As the model or its components can be transported with minimum space requirements, it can be made available even to remote areas. This is of gaining importance as pericardial effusion and consecutive tamponade, occurring in up to 20%, in developing countries are mostly caused by infectious diseases such as tuberculosis which is regarded as an epidemic in some areas [13].

In contrast to Zerth et al. [11], we performed a standardized evaluation of our model using a questionnaire. Although our pericardiocentesis model was rated only as valuable by the study participants in most regards, it shows clear feasibility and can enrich specialised ultrasound training. However, the lack of a realistic appearance of the phantom itself and the heart was assessed as a weakness. Practicing pericardiocentesis with our model gave the participants more confidence for further interventions whenever in the future they have to perform one.

5. Limitations

Our study is limited by the fact that most of the study participants did not have experience with pericardiocentesis and thus could not compare the model to “real life” circumstances. Another limitation is that surprisingly there was no difference between the group of physicians experienced in pericardiocentesis and the group without any experience with punctures of any kind, showing that this can only be of subordinate impact.
6. Conclusion

Our low-cost pericardiocentesis model, which can be easily constructed, may serve as an effective training tool of ultrasound-guided pericardiocentesis for acute and critical care physicians.

Authors’ Contribution

Marco Campo dell’Orto and Dorothea Hempel contributed to the paper equally and shared the first authorship.

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References


Nonconcordance between Clinical and Head CT Findings: The Specter of Overdiagnosis

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Background. It is unclear whether history and physical examination findings can predict abnormalities on head computed tomography (CT) believed to indicate increased risk of lumbar-puncture- (LP-) induced brain herniation. The objectives of this study were to (1) identify head CT findings felt to be associated with increased risk of brain herniation and (2) to assess the ability of history and physical examination to predict those findings. Methods. Using a modified Delphi survey technique, an expert panel defined CT abnormalities felt to predict increased risk of LP-induced brain herniation. Presence of such findings on CT was compared with history and physical examination (H&P) variables in 47 patients. Results. No H&P variable predicted “high-risk” CT; combining H&P variables to improve sensitivity led to extremely low specificity and still failed to identify all patients with high-risk CT. Conclusions. "High-risk" CT is not uncommon in patients with clinical characteristics known to predict an absence of actual risk from LP, and thus it may not be clinically relevant. "Overdiagnosis" will be increasingly problematic as technological advances identify increasingly subtle deviations from “normal.”

1. Introduction

There is substantial evidence in the medical literature that lumbar puncture (LP) is extremely safe [1–3], particularly in the setting of patients who are immunologically normal and who do not manifest abnormal mental status, papilledema, or focal neurological deficit [3–5]. Nevertheless, many clinicians are concerned that LP could lead to tonsillar herniation [6–11] in patients with increased intracranial pressure (ICP), by decreasing cerebrospinal fluid pressure in the subarachnoid space, and thus creating a pressure gradient that could displace cerebral and brainstem structures [7, 12].
There are only a small number of reports, however, suggesting catastrophic deterioration related to LP [9, 13, 14], and even the validity of these observations has been questioned [15–17]. Nevertheless, despite the substantial evidence that few, if any patients, are at risk from LP, many clinicians worry about potential harm, and it has been suggested that head computed tomography (CT) be obtained prior to LP, in the hope that it might be able to identify the few patients in whom the procedure would purportedly be dangerous [5, 18]. There are no studies, however, which define what if any findings on head CT actually do predict increased risk of tonsillar herniation following LP [3, 4, 19].

We designed this study to assess the prevalence of “high-risk” CT findings in patients who undergo head CT for any reason and in particular whether and how often such findings occur in patients whose clinical presentations make it extremely unlikely that they would be harmed by LP. Because of the absence of any gold standard for “high-risk” CT findings, we convened an expert panel and asked its member to define what CT findings indicate increased risk of tonsillar herniation following LP; we then used clinical data that had been prospectively recorded on a large cohort of patients for whom CT had been ordered to assess the relationship between selected history and physical examination (H&P) findings and the presence of those CT characteristics defined by the expert panel as conferring increased risk.

2. Methods

2.1. Ethics Statement. This study was approved by the University of California, Los Angeles (UCLA) Institutional Review Committee. Informed consent was not required as the clinical data collected was deidentified and did not impact clinical care.

2.2. Study Design. We designed this study in two parts. First, given the absence of any prior criterion standard regarding which if any head CT findings predict increased hazard from performance of LP, we convened an expert panel to determine if it was possible for them to agree on any set of head CT characteristics that could be defined as predicting “high risk” of LP-induced brain herniation (Part I). Second, we used prospectively collected data from the large NEXUS 2 cohort of emergency department patients for whom head CT had been ordered, for whatever reason, to evaluate how closely clinical findings correlate with the presence or absence of any of these “high-risk” CT findings (Part II). We did not make any assumptions regarding what would have happened to any of the individual patients in our study had an LP been performed on them. (We did assume, on the other hand, based on substantial evidence from the literature, that at most a very few patients in this cohort might have been harmed by LP, particularly among that subset of patients who had been prospectively found not to have papilledema, altered mentation, or focal neurological findings.)

Part I: The Modified Delphi Technique to Define Predictive Head CT Abnormalities. We employed a modified Delphi survey technique [20–23] to allow a group of content experts, who perform LP and/or interpret head CT regularly, to generate a list of head CT abnormalities that they believed to predict high risk of herniation with LP and thus contraindicate this procedure. Of the 16 physicians asked to participate, 13 agreed. The panel included academic physicians in emergency medicine (2), internal medicine (1), infectious disease (1), neurology (4), neurosurgery (2), and radiology (3) including one general radiologist, one neuroradiologist, and one emergency radiologist, from four academic medical centers in the Midwest and the West Coast of the United States.

A structured e-mail survey regarding potential LP contraindications was sent to the panelists, each of whom then indicated his or her level of agreement (0 = "strongly disagree," and 5 = "strongly agree") with the following statement: “This CT finding should contraindicate performance of an LP” for a series of possible CT findings (see Appendix information at "Information and Survey Sent to the Delphi Panel"). Narrative explanations of the experts’ responses were solicited, and panelists were asked to suggest any additional CT findings they felt should contraindicate LP. For subsequent rounds, survey participants were asked to read the anonymous narrative explanations submitted by all of the panelists and then to rereat each CT finding. While three survey rounds are generally considered adequate to achieve a valid consensus opinion [24], when an additional potential LP contraindication was first suggested in the third round, one final survey round was added. Panelists were blinded to the identities of other panel members, but they were allowed to use outside references and to discuss the survey with colleagues. In order to maximize sensitivity, we included in the final list of “contraindications” any finding assigned a level of 4 or 5 by one-third of the panelists.

Part II: Study Subjects. We included all of the 1737 patients for whom a head CT scan had been ordered at an academic, urban, level I emergency department (ED) between April 2006 and February 2007, as part of a prior study in which the treating clinician prospectively recorded the presence or absence of specific H&P findings at the time the CT was ordered and before it was actually done [25]. The only exclusion criterion was a history of a prior neurosurgical intervention. A neuroradiologist interpreted all CT images. Two physician reviewers, blinded to H&P findings, then independently classified the written head CT radiology reports as reflecting that the patient either was at increased risk (if any of the expert panel’s increased-risk findings were present (Table I)) or was not at increased risk (if none of these findings were present). When both reviewers independently agreed that the written report was definitive regarding presence or absence of the increased-risk findings, they were classified as such. In any case where either of the physicians was uncertain on how to classify this, based solely on the written report, the actual CT images were reviewed by an expert radiologist, who then prospectively characterized each study with regard to the presence or absence of increased-risk findings. If the emergency radiologist was uncertain, a senior emergency
physician conducted an additional review of the CT images. To be as conservative as possible in these few remaining, this physician labeled the CT scan as showing “increased risk” only if any one of the following additional findings was present: dilation, enlargement or compression of the 4th ventricle or the brainstem, hydrocephalus, effaced cerebral sulci, local mass effect, or evidence of edema.

2.3. Primary Data Analysis. We calculated the sensitivity, specificity, and positive and negative predictive values for each of the individual H&P findings in predicting the presence of increased risk of herniation with LP on head CT (as defined by the expert panel). We also analyzed the test characteristics of the complete neurologic examination and all aspects of the H&P, assuming that the presence of any single abnormal finding predicts increased risk as determined by CT.

3. Results

3.1. Part I: The Modified Delphi Results. The expert panel ultimately agreed on five findings on head CT that were felt to increase risk of LP sufficiently so as to contraindicate performance of this procedure (Table 1). There was complete agreement on inclusion of subtentorial or tonsillar herniation, strong agreement on obliteration of the fourth ventricle, and majority agreement on lateral shift of midline structures and loss of basal cisterns; a sufficient minority (at least one-third of the panel) felt that the obliteration of the superior cerebellar cistern and the quadrigeminal plate cistern should be included. Three other findings (isolated dilation of the temporal horns of the lateral ventricles, intracranial abscess in an immunocompromised patient, and Chiari I malformation with a tethered cord) had at least one vote for inclusion, but they were ultimately excluded because they were not endorsed by an adequate number of panelists.

3.2. Part II: Study Subjects Results. Of the 1737 patients initially included, 445 had abnormal head CTs. Of these, 122 were excluded because of a previous neurosurgical intervention, leaving 323 patients for the final analysis. The average age of study subjects was 57.8 years (range, 1–99 years), and 58% were male. Other demographic characteristics are listed in Table 2.

In categorizing the CT scan reports, both of the physician reviewers independently agreed that the written radiology report definitively indicated the presence, or absence, of the high-risk findings, in 68% of the cases. The emergency radiologist who then reviewed the actual CT images in the remaining 32% of cases was able to categorize findings as clearly present or absent in all but 2%; these few cases were then categorized by a senior emergency physician, using the conservative criteria described above (with cases classified as high risk only if they showed definitive dilation, enlargement or compression of the 4th ventricle or the brainstem, hydrocephalus, effaced cerebral sulci, local mass effect, or evidence of edema). Overall, 47 (14.6%) of the CT scans had at least one of the high-risk findings defined by the expert panel (Figure 1).

None of the individual elements of H&P were sensitive in identifying patients with increased risk based on head CT findings (Table 3). The highest sensitivity for any single clinical characteristic was 68.9% (CI 53.4, 81.8), for presence of a focal neurological deficit on examination; this finding had a specificity of 73.5% (CI 67.8, 78.7). When the neurological examination was considered as a whole, with the presence of any single abnormality on examination compared with presence or absence of high-risk CT, sensitivity was still only 87.0% (CI 73.7, 95.1), and specificity was 39.3% (CI 33.5, 45.3). If the presence of any single abnormality on either history or physical examination was considered positive, sensitivity was increased to 95.7% (CI 85.5, 99.5), but specificity was further decreased to only 17.8% (CI 13.5, 22.9); this approach still failed to identify 2 of 47 patients with “high-risk” CT findings.
Table 3: Test characteristics of history and physical examination findings in relation to clinically abnormal head CTs.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Sensitivity CI</th>
<th>Specificity CI</th>
<th>NPV CI</th>
<th>PPV CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blunt head injury</td>
<td>139/307</td>
<td>47.7 (32.5, 63.3)</td>
<td>55.1 (48.9, 61.3)</td>
<td>86.3 (80.2, 91.1)</td>
<td>15.1 (9.6, 22.5)</td>
</tr>
<tr>
<td>Dangerous mechanism</td>
<td>105/285</td>
<td>33.3 (19.6, 49.6)</td>
<td>62.6 (56.1, 68.7)</td>
<td>84.4 (78.3, 89.4)</td>
<td>13.3 (7.5, 21.4)</td>
</tr>
<tr>
<td>Vomiting</td>
<td>23/318</td>
<td>8.9 (2.5, 21.2)</td>
<td>93 (89.4, 95.8)</td>
<td>86.1 (81.6, 89.3)</td>
<td>17.4 (5.0, 38.7)</td>
</tr>
<tr>
<td>Coagulopathy</td>
<td>36/280</td>
<td>8.3 (1.8, 22.5)</td>
<td>86.5 (81.5, 90.5)</td>
<td>8.3 (1.8, 22.5)</td>
<td></td>
</tr>
<tr>
<td>Skull fracture</td>
<td>21/319</td>
<td>11.6 (3.8, 24.6)</td>
<td>94.2 (90.7, 96.6)</td>
<td>86.9 (82.6, 90.5)</td>
<td>23.8 (8.2, 47.2)</td>
</tr>
<tr>
<td>Scalp hematoma</td>
<td>81/319</td>
<td>26 (14.2, 41.1)</td>
<td>74.7 (67.9, 79.8)</td>
<td>85.7 (80.6, 89.9)</td>
<td>14.8 (7.9, 24.5)</td>
</tr>
<tr>
<td>Neuro deficit</td>
<td>102/313</td>
<td>68.9 (53.4, 81.8)</td>
<td>73.5 (67.8, 78.7)</td>
<td>93.4 (89.1, 96.3)</td>
<td>30.4 (21.7, 40.3)</td>
</tr>
<tr>
<td>ALOC</td>
<td>134/316</td>
<td>67.4 (52.0, 80.5)</td>
<td>61.9 (55.8, 67.7)</td>
<td>91.8 (86.8, 95.3)</td>
<td>23.1 (16.3, 31.2)</td>
</tr>
<tr>
<td>Abnormal behavior</td>
<td>100/314</td>
<td>53.3 (37.9, 68.3)</td>
<td>71.8 (66.0, 77.1)</td>
<td>90.2 (85.4, 93.8)</td>
<td>24 (16.0, 33.6)</td>
</tr>
<tr>
<td>No spontaneous eye opening</td>
<td>61/316</td>
<td>34.1 (20.5, 49.9)</td>
<td>83.1 (78.1, 87.3)</td>
<td>88.6 (88.1, 92.3)</td>
<td>24.6 (14.5, 37.3)</td>
</tr>
<tr>
<td>Not oriented</td>
<td>189/305</td>
<td>65.1 (49.1, 79.0)</td>
<td>66.4 (60.3, 72.1)</td>
<td>92.1 (87.3, 95.5)</td>
<td>24.1 (16.7, 33.0)</td>
</tr>
<tr>
<td>Not following commands</td>
<td>76/310</td>
<td>43.2 (28.3, 59.0)</td>
<td>78.6 (73.2, 83.4)</td>
<td>89.3 (84.6, 93.0)</td>
<td>25 (15.8, 36.3)</td>
</tr>
<tr>
<td>Amnestic</td>
<td>28/224</td>
<td>18.5 (6.3, 38.1)</td>
<td>88.3 (83.0, 92.5)</td>
<td>88.8 (83.5, 92.8)</td>
<td>17.9 (6.1, 36.9)</td>
</tr>
<tr>
<td>Combined criteria</td>
<td>271/322</td>
<td>95.7 (85.5, 99.5)</td>
<td>17.8 (13.5, 22.9)</td>
<td>96.1 (86.5, 99.5)</td>
<td>16.6 (12.4, 21.6)</td>
</tr>
<tr>
<td>Abnormal neuro exam</td>
<td>207/321</td>
<td>87 (73.7, 95.1)</td>
<td>39.3 (33.5, 45.3)</td>
<td>94.7 (88.9, 98.0)</td>
<td>19.3 (14.2, 25.4)</td>
</tr>
<tr>
<td>Abnl neuro exam or vomiting</td>
<td>217/321</td>
<td>87 (73.7, 95.1)</td>
<td>36 (30.3, 42.0)</td>
<td>94.3 (88.0, 97.9)</td>
<td>18.5 (13.6, 24.4)</td>
</tr>
</tbody>
</table>

N: number, CI: confidence interval, PPV: positive predictive value, NPV: negative predictive value, Abnl: abnormal, and Neuro: neurological.

**Figure 1: Study subject selection.**

4. Discussion

There is substantial evidence in the medical literature that brain herniation secondary to lumbar puncture is extremely uncommon; this is particularly true among patients who do not have high-risk clinical findings, such as altered mentation or focal neurological deficits. Because of concerns about this catastrophic possibility, however, several authors have suggested that head CT scanning be performed prior to LP, to help identify patients at increased risk. Because of the absence of any prior criterion standard regarding “high-risk” CT findings, we performed Part I of our study to define a group of such findings about which experts would agree that they represent an increased risk of LP-induced brain herniation on head CT findings. Using standard accepted methodology of a modified Delphi technique, our expert panel was able to reach consensus, and at least one of their “high-risk” findings was present in about one of every seven patients in our cohort; a majority of these patients at “high risk” as indicated by their CT findings had clinical findings (as prospectively recorded) that suggested very little or no actual likelihood of danger from LP. The method used to characterize high-risk findings on CT scans (to rely on written radiology reports only when they were definitive and to have images prospectively reviewed when such written reports were not absolutely clear) was intentionally conservative and intended to bias against our hypothesis that CTs lead to overdiagnosis by showing “high-risk findings.” While we of course cannot know with any certainty what would or would not have happened to any individual in our cohort had he or she been subjected to LP, it is clear that this number is far larger than the rate of deterioration that should be expected amongst this group.

There are two very different possible explanations for this discordance between clinical findings in individual patients and “high-risk” elements on CT. One explanation is based on the assumption that when a technologically advanced test like CT identifies some problem not identified by clinical exam, the former always provides more accurate evidence of the patient’s true condition; this type of reasoning is extremely widespread in modern medical practice. In the clinical scenario addressed by our study, that would mean that clinical findings are insufficient to identify patients in whom LP would be dangerous—and that CT should be performed routinely prior to LP—to identify a substantial group of patients with a clinically occult risk from this procedure. However, it is also possible that CT findings (as defined by this expert panel and as reflected in opinion papers in the medical literature [14]) are overly sensitive and identify a fairly large group of patients the large majority of whom are not in fact at any risk. It is not possible to say with certainty which of these
interpretations is correct, based on this or any other currently available study.

We believe that this disjunction between sophisticated technology and traditional diagnostic evaluation is not unique to head CT scanning and the risk of herniation and that the importance of our findings extends far beyond the narrow question of whether routine imaging (which also carries well-described medical and economic costs [3, 26, 27]), prior to LP, would on balance be beneficial or harmful. Modern technological approach to pulmonary embolism (PE), for example, has led to a vast increase in the number of patients given this diagnosis, but a concomitant vast decrease in the case-fatality rate associated with it [28], which appears to be largely independent of any benefit from advances in treatment. In addition, a recent decision analysis suggests that while an effort to identify PE in a cohort of reasonably low-risk patients using CT angiography may benefit a few patients, it will harm many more, increasing not only morbidity but also mortality [28]. Our observations about the use of CT to predict risk of brain herniation should thus be viewed in terms of this much larger question about technology in general and suggest that this question needs urgent attention from both the research community and the practicing physicians, since simply assuming that the former must be a better “gold standard” may in fact lead to major harm to patients [28, 29].

Although it is tempting to assume that technology is both more reliable and more accurate than clinical examination, there are several reasons to question this belief. First, there are numerous examples where some finding identified by some type of advanced technology is given the same name as a previously well-known clinical event, but it actually implies a far less dangerous clinical entity. As in the case of PE, described above, a hyphema diagnosed by slit-lamp examination is less worrisome (and should be approached differently) than a hyphema visible to the naked eye; similarly, CT-defined pneumothorax is clinically different than pneumothorax seen on a chest X-ray, acute myocardial infarction (MI) defined on the basis of troponin leak is not the same as the clinically apparent MI, and asymptomatic microscopic prostate “cancer” diagnosed by biopsy, after screening, implies a very different prognosis (and should be approached differently) than does cancer searched for and found because of clinical symptoms.

With regard to the specific clinical issue raised in our study, a recent publication reported head CT “evidence of herniation” in many patients who were clinically entirely stable [30]. The meaning of such “herniation” is obviously different than is tonsillar herniation associated with catastrophic clinical deterioration. Because clinicians have long used clinical findings to decide who can safely undergo LP without a head CT and because with this approach tonsillar herniation rarely if ever occurs (especially in patients with normal mental status and no focal deficit), we believe that the CT criteria defined by our experts are likely to be overly sensitive and identify “risk” in many patients who could undergo LP with almost no chance of clinical deterioration.

Since clinical brain herniation almost inevitably results in death, it is appropriate that CT criteria for safe performance of LP should err on the side of high sensitivity. On the other hand, failure to recognize that “findings” on head CT may not have the meaning traditionally attributed to the same “abnormalities” (“lesions” and “diseases”) identified on the basis of clinical condition could lead to dramatic overdiagnosis [29], which could in turn result in substantial harm to patients. In our scenario, this could lead to an insistence on routine CT scanning prior to LP, despite the long history of safe performance of LP without CT; furthermore, findings on those CT scans would almost certainly then lead to avoidance of LP in many patients in whom this test would not only be enormously safe but could also provide important diagnostic information.

In a broader sense, our study raises generic concerns about the danger of assuming that as technology advances, it will always provide a better and better diagnostic gold standard. We can easily envision, for example, a time when the Nth generation CT scanners, using electron microscope-type resolution, might identify a “thyroid nodule” in just about everyone—which might be proved on biopsy to be “cancer” in many—even though the vast majority would never know about this “cancer” had the “advanced imaging” not been performed. The same could be true for “renal cysts”, or lesions on supermammography, or even “pulmonary emboli” in many if not all normal pulmonary arteries leading to obvious and profound conundrums about both the meaning of such findings and the appropriate way to separate disease, which might benefit from treatment, from overdiagnosis of normal (or at least clinically unimportant) variation. Surveillance bias has been described as “the more you look, the more you find;” [31]. The type of overdiagnosis we believe we have identified appears to be a closely related variant, where “the closer you look (with more and more powerful tools), the more you find.”

The head CT criteria defined by our panel as representing “increased risk” of herniation are based on expert opinion, rather than experimental evidence, which does not exist. Although many specialties were represented in the expert panel, not all regularly perform LP, which may have resulted in an overly conservative list of “contraindications.” Our expert panel also suffered a degree of expert attrition, with one neurosurgeon, one neurologist, and one neuroradiologist failing to complete the entire sequence of surveys. Peer pressure can influence expert panels [32], so this could conceivably have biased our results.

Nevertheless, our study provides strong evidence that no H&P findings, alone or in combination, are adequately sensitive to detect head CT abnormalities believed by a panel of experts to predict enhanced potential for brain herniation during LP. Since clinical brain herniation is extremely rare following LP and these CT findings are far more common, it is likely that these criteria are overly sensitive and that their application to patients needs to be reconsidered. Furthermore, our study suggests that there is an urgent need to question the assumption that “advanced” technology defines the criterion standard when there is a clear disjunction between abnormalities defined clinically and “abnormalities”
given the same name, despite an absence of clinical correlates, when identified by such technology.

Appendix

Information and Survey Sent to the Delphi Panel

Dear Colleague:

Thank you for agreeing to be part of an expert panel to help determine CT contraindications to LP. This is round 1 of 3 questionnaires regarding the topic.

For the following 3 items:

1. Please indicate your level of agreement that the CT finding listed is a contraindication for performing an lumbar puncture using a 5 point scale (0 indicates strong disagreement and 5 strong agreement).

2. Please explain the reasons for your choice in the space provided.

3. Please add any additional CT findings that are contraindications to LP you feel should be on the list.

Please return this questionnaire by email or fax.

Your Name: ____________________________

1. The CT finding of a lateral shift of the midline structures is a contraindication to performing an LP.

   Strongly disagree 0 1 2 3 4 5 Strongly agree

   Your level of agreement with statement #1: ________

   Please explain the reason(s) for your answer:

2. The CT finding of a loss of the basilar cisterns is a contraindication to performing an LP.

   Strongly disagree 0 1 2 3 4 5 Strongly agree

   Your level of agreement with statement #2: ________

   Please explain the reason(s) for your answer:

3. The CT finding of an obliteration of the fourth ventricle is a contraindication to performing an LP.

   Strongly disagree 0 1 2 3 4 5 Strongly agree

   Your level of agreement with statement #3: ________

   Please explain the reason(s) for your answer:

4. The CT finding of an obliteration of the superior cerebellar cistern and the quadrigeminal plate cistern with sparing of the ambient cisterns is a contraindication to performing an LP.

   Strongly disagree 0 1 2 3 4 5 Strongly agree

   Your level of agreement with statement #4: ________

   Please explain the reason(s) for your answer:

5. Please suggest any additional CT findings that are contraindications to LP that you feel should be included in this list, and briefly explain why.

Disclosure

No direct funding was received for this study. The authors were personally salaried by their institutions during the period of writing (although no specific salary was set aside or given for the writing of this paper).

Conflict of Interests

The authors declare that they have no conflict of interests.

Authors’ Contribution

William R. Mower, Steven Go, and Kelli N. O’Laughlin conceived and designed the study. Steven Go supervised the expert panel process and data collection. William R. Mower and Guy Merchant supervised the collection and management of data related to head CTs and radiology reports. Kelli N. O’Laughlin, Gelareh Z. Gabayan, Erum Iqbal, and Roberto A. Lopez-Freeman assisted with data collection. Kelli N. O’Laughlin and Gelareh Z. Gabayan categorized radiology reports, and Michael Zucker and Jerome R. Hoffman served as arbitrators. Kelli N. O’Laughlin analyzed the data and William R. Mower served as senior advisor providing guidance on data analysis. Kelli N. O’Laughlin drafted the paper except for the sections related to the expert panel, which were drafted by Steven Go. Jerome R. Hoffman revised the paper (including particularly the Discussion), Gelareh Z. Gabayan participated in paper revision, and Kelli N. O’Laughlin, Jerome R. Hoffman, and William R. Mower took responsibility for the final paper revisions. Kelli N. O’Laughlin, Jerome R. Hoffman, and William R. Mower took responsibility for the paper as a whole.

References


Clinical Study

Does Radar Technology Support the Diagnosis of Pneumothorax? PneumoScan—A Diagnostic Point-of-Care Tool


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Background. A nonrecognized pneumothorax (PTX) may become a life-threatening tension PTX. A reliable point-of-care diagnostic tool could help in reduce this risk. For this purpose, we investigated the feasibility of the use of the PneumoScan, an innovative device based on micropower impulse radar (MIR), Patients and Methods. addition to a standard diagnostic protocol including clinical examination, chest X-ray (CXR), and computed tomography (CT), 24 consecutive patients with chest trauma underwent PneumoScan testing in the shock trauma room to exclude a PTX. Results. The application of the PneumoScan was simple, quick, and reliable without functional disorder. Clinical examination and CXR each revealed one and PneumoScan three out of altogether four PTXs (sensitivity 75%, specificity 100%, positive predictive value 100%, and negative predictive value 95%). The undetected PTX did not require intervention. Conclusion. The PneumoScan as a point-of-care device offers additional diagnostic value in patient management following chest trauma. Further studies with more patients have to be performed to evaluate the diagnostic accuracy of the device.

1. Introduction

Thoracic trauma is frequent in multiple traumatized patients. According to the current annual report of the TraumaRegister of the German Trauma Society (DGU) 56% of 10766 documented severe trauma patients with Injury Severity Score (ISS) ≥ 16 points showed thoracic injuries with an Abbreviated Injury Scale (AIS) ≥ 3 points [1]. Beside rib fractures, lung contusion and PTX are the main consequences of blunt chest trauma. In hospital, significant PTX is detected between 37 and 59% of the cases [2]. Primary routine diagnostics in shock trauma room include a clinical examination and conventional CXR. However, a significant percentage of PTX maintains undetected by these methods and is first distinguished by CT scan. The number of occult PTXs range from 2 to 15% [3–5], in some studies even 50% [6]. Therefore the “S-3 guideline on treatment of patients with severe and multiple injuries of the DGU” recommends expanding radiologic diagnostics by thoracic ultrasound (eFAST) when suspecting thoracic trauma. If significant clinical signs are present a thoracic CT scan with i.v. contrast agent is advised, alternatively even primary [2]. CXR, and CT scan only are available in hospital and ultrasound is not used regularly in the prehospital setting. Therefore, only mechanism of injury, and clinical examination with assessment of ventilation can be consulted for diagnosing or excluding PTX. Due to low sensitivity (43–90%) and specificity (79–98%) of each single criterion, only their combination allows secure assessment [2, 7, 8].

Circumstances as mass casualty incident (MCI) could rapidly restrict clinical established diagnostics by limiting
available resources. Further on, a CBRN (chemical, biological, radiological, and nuclear) attack can cause massive delay of treatment, as decontamination of victims is the primary focus.

The initial, secure, and fast detection or exclusion of PTX has however a high impact on the management, especially if continuous monitoring and immediate treatment of PTX through chest tube placement cannot be guaranteed [2, 7, 8].

An anytime bedside available, examiner-independent, easy to use, and fast method with high diagnostic accuracy in terms of a point-of-care device to rule out PTX would be desirable [7]. Therefore, an innovative and nonionizing micropower impulse radar- (MIR-) based tool—the PneumoScan engineered by PneumoSonic Inc. (Cleveland, OH, USA)—is investigated to exclude PTX in the context of shock trauma room treatment of severely injured patients.

2. Patients and Methods

2.1. PneumoScan. Based on micropower impulse radar (MIR), the PneumoScan is a portable, battery-powered, CE-certified (CE certificate 561036) diagnostic tool, available via PneumoSonic Inc. (Cleveland, OH, USA). It emits extremely low-power ultrashort electromagnetic signals with a frequency of 500 megahertz to six gigahertz [9]. Those ultrawideband (UWB) signals can penetrate different materials like human tissue. Each tissue (e.g., fat, muscle, and bone) reflects these waves differently. The in-built receiver of PneumoScan analyses those specific reflections. Thereby, abnormal conditions like a PTX can be detected [10]. The Lawrence Livermore National Laboratory (Livermore, CA, USA) examined the physiologic reflection pattern of the lung in healthy patients and compared the results to those with PTX condition. Thereby, baseline data were gained and defined. By using specific algorithms the software of PneumoScan correlates received patient-specific signals with baseline data [10].

Spatial accuracy of PneumoScan amounts approximately five millimetres, penetration depth approximately seven centimetres. The impulses also can penetrate textiles to allow an examination of a dressed patient [11]. Transients of other technical devices are suppressed by combination of broad frequencies, low power demand, and emission of very short impulses. The functions of electronic devices such as a cardiac pacemaker are not affected.

The device consists of two pieces: the MIR transceiver with antenna and processor (Figure 1, right), as well as a portable handheld computer, for example, Motorola MC75 (Figure 1, left).

The PneumoScan analyses signals of eight specific sites along the anterior thorax (Figure 2). Total scan time is one to two minutes. Each correct scan is signalized visually and acoustically. After eight completed scans, the result with localisation (right or left lung) is displayed by red (PTX) or green (no PTX) colour coding (Figure 3).

2.2. Study Procedure. Between May and June 2011, 24 severely injured adult patients with blunt or penetrating chest trauma, admitted via shock trauma room, were included in the survey in a level-one trauma centre. Treatment was standardized according to Advanced Trauma Life Support (ATLS) protocol. Primary imaging diagnostics were conducted in shock trauma room by CXR (Lodox Statscan, Lodox Systems (Pty) Ltd, Benmore, South Africa) and secondarily after shock trauma treatment by full body spiral CT with contrast agent (Somatom Sensation 16, Siemens AG, Erlangen, Germany) [12].

Referring to our question, application of PneumoScan to exclude a PTX was conducted additionally in shock trauma room. Scans were performed by two physicians and two medical students after a 15-minute instruction tutorial. PneumoScan measurements took place during clinical examination, but before CXR and CT scan (scans on all included patients were performed within first 15 minutes), to avoid falsification of results through a potentially growing PTX in following examinations. PneumoScan results were blinded to the examiner (no real-time display of the results) and performed without knowledge of CXR and CT findings.

Chest CT was used as gold standard in all examinations. By CT scan detected PTX were classified through their maximal extension in axial slices (maximal distance of visceral pleura to parietal pleura) and through their position (anterior/lateral/posterior).

3. Results

In total, 24 severely injured patients (ISS ≥ 3 points) with nearly exclusive blunt chest trauma (96%) were enrolled. Eighty-eight percent were male. Mean age was 47 years (Table 1).
Four one-sided PTXs were diagnosed by CT scan, three of them on the right side, one on the left side. Clinical examination and CXR detected one PTXs. Through PneumoScan, three PTXs were detected, whereof two PTXs were clinically significant (treated with chest tube placement) (Table 2).

One maximal 20-millimetre large anterior PTX with no need for chest tube placement was neither detected by PneumoScan nor by clinical examination or CXR.

The sensitivity of PneumoScan measurements amounted to 75%, with specificity 100%. The prevalence of PTX was 17%. The positive predictive value was 100% and negative predictive value 95% (Table 3).

4. Discussion

In our study we were able to show that the MIR-based PneumoScan as a point-of-care device could be a helpful tool for detecting PTX, in context of shock trauma room management following ATLS protocol. Despite low number of cases, we revealed at least a principle advantage of PneumoScan towards clinical examination and CXR in excluding PTX, which could increase diagnostic safety. The results of this study with 24 applied patients underline the good findings of a previous study with 50 patients to assess the diagnostic value of PneumoScan (sensitivity 85.7% (1/7 false negative), specificity 97.7% (1/43 false positive), gold standard CT [13]).

The only undetected PTX by PneumoScan was neither revealed by clinical examination nor by CXR. The body mass-index (BMI) of this patient (lowest BMI of all enrolled patients) contradicts considerations that PneumoScan might not penetrate tissue deep enough (penetration depth of PneumoScan: seven centimetres). Refering to CT, maximum extension of the unrevealed PTX was larger than the smallest PTX detected by the device (spatial accuracy of PneumoScan: five millimetres). One could assume that this particular PTX developed itself in time course. The undetected PTX was not significant (no chest tube placement needed) in clinical course.

On scene, emergency physicians and emergency medical technicians (EMT) can only adequately detect a traumatic PTX by combining single findings of clinical examination [7, 8]. Even if present studies report that a wait-and-see attitude in occult PTX (even in ventilated patients) can be as safe as chest tube placement [14, 15], it is not clear which kind of cases are applicable to this statement [5]. In principle, every PTX can develop life-threatening complications any time. An early and safe exclusion or detection of PTX would constitute an advantage in treatment, in terms of a better risk assessment of the patient. Focused assessment sonography for trauma (FAST) is integrated in ATLS protocol to exclude free abdominal fluid. By simply expending the examination to the chest, ultrasound could be used for PTX diagnostics, also
in the preclinical setting. However, different studies showed high specificity (approximately 99%), but fluctuating sensitivity (47–100%, pooled sensitivity: 88%) [16]. Furthermore, ultrasound diagnostic is highly examiner-dependent and not practicable for untrained personnel [16–19]. Especially in case of mass casualties rescue teams need to triage patients in a very limited time. Therefore, a reliable and compact point-of-care diagnostic tool with an easy handling is desirable [7]. In a previous study examining the diagnostic value of PneumoScan, all measurements were conducted by only two physicians [13]. In the present study two medical students were able to perform and interpret readings with the PneumoScan only after a 15-minute tutorial which definitely states an advantage towards ultrasound. Regarding the frequency of traumatic PTX [2] and the diagnostic weakness of CXR [3–6], PneumoScan even seems to be a reasonable addition or alternative to chest ultrasound in the primary survey (Breathing) of shock trauma room management. Improved preclinical diagnostic possibilities may reduce “preventive” (Breathing) of shock trauma room management, especially preclinical use and disaster medicine are potential fields of operation.

5. Conclusion

Further clinical and preclinical surveys with a bigger population of patients are required to evaluate the diagnostic accuracy of PneumoScan in detection of PTX. Basically, the MIR-powered device offers a fast point-of-care method, which on top is easy to use only after a short tutorial. Beside shock trauma room management, especially preclinical use and disaster medicine are potential fields of operation.

**Disclosure**

Two PneumoScan devices exempt from charges were provided by PneumoSonics Inc. (Cleveland, OH, USA). All costs for ethical vote were accepted by the company. Dr Levy is a consultant for PneumoSonics Inc and has an equity interest in the company. Dr Levy was not involved in the measurements. All other authors declare no conflict of interests regarding the publication of this article.

**References**


Full-Body X-Ray Imaging to Facilitate Triage: A Potential Aid in High-Volume Emergency Departments

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The levels of traumatic injury seen in South African emergency departments (EDs) are epidemic. This is coupled with a severe lack of resources and adequately trained emergency staff. The Lodox Statscan (LS) is an X-ray scanner capable of producing rapid, low-dose, and full-body X-ray images. In this paper, a new trauma protocol—the Johannesburg trauma protocol—that implements LS scanning on entry to the ED as a triage tool is reported. A case study illustrating the use of LS to triage 63 patients in a single Saturday shift at a level 1 Trauma Centre is also presented. Because of the ability to rapidly and safely provide X-ray imaging information to support clinical decision making, the LS could be a useful tool to aid in resource allocation to improve treatment of the high levels of trauma patients that present to South African EDs daily.

1. Introduction

Low- and middle-income countries account for more than 90% of global deaths from injuries. Amongst these countries is South Africa which experiences a uniquely high and violent rate of trauma. Well-documented data on the exact numbers of injuries, deaths and the underlying causes are lacking. However, some figures suggest trauma loads of between 16,357 and 24,113 on primary (Level 1) Trauma Centres per year [1–3]. Nationally, 46% of these are attributed to homicides, 26.7% to road traffic accidents (RTA), and 9.1% to self-inflicted injury. The homicide rate alone is nine times greater than the global average [4].

Coupled with this significantly high rate of trauma is the severe lack of resources and staffing. South Africa’s history of apartheid has left a legacy of oversubscribed, underfunded, and poorly equipped state hospitals, dealing with more than 80% of the population’s health requirements with just 25% of total healthcare expenditure [5]. Funding restrictions, together with the harsh working environment, also result in a severe shortage of adequately trained emergency staff. In South Africa, the doctor to nurse ratio is twice that for Canada and almost five times that for Israel. Possibly more disturbing, South Africa has more than four times fewer doctors per 100,000 population than countries like Canada and Australia [6].

The two effects—high patient volumes and low resource availability—often combine to create almost warfare-like trauma situations in South African emergency departments (EDs) [7]. In response, some unique trauma mechanisms have been adopted. Among these are greater reliance on a first principles diagnostic approach and a unique triage scoring system to assist with resource allocation—the South African Triage Scale (SATS) [8]. Also in use in most of South Africa’s Level 1 Trauma facilities is a South African designed high-speed, full-body, and low dose X-ray machine (Lodox Statscan, Lodox System Pty Ltd, Johannesburg, South Africa—LS), which has been shown to dramatically reduce primary survey and resuscitation times [9,10].

This report aims to examine the role of this high-speed, full-body radiography system on the trauma protocol in one of South Africa’s busiest hospitals and its effect on the triage and treatment process during the frequently occurring “mini” mass disasters that characterise the South African trauma
environment. This is coupled with a view to informing global protocol for isolated multiple-casualty situations and in other environments with a high trauma burden.

2. Methods

An examination of the trauma protocol and response in a Tertiary Level 1 Trauma hospital in Johannesburg, South Africa, was undertaken. The trauma workflow in that hospital is presented, as well as a case study illustrating the use of full-body radiography in a high-volume trauma situation.

2.1. System Description. The LS (Figure 1) has an X-ray tube, mounted on one end of a C-arm that emits a focused, collimated fan-beam of X-rays. The X-ray detector unit, on the opposite end of the C-arm, consists of scintillator arrays optically linked to charge-coupled devices [11]. The C-arm takes 13 seconds to travel linearly along the table length, and a full-body (1.8 m) anterior-posterior digital scan is available in less than 1 minute. The C-arm can be rotated axially around the patient to any angle up to 90° to allow subsequent shoot-through lateral and oblique views to be taken. The unit includes a moveable, docking resuscitation trolley to eliminate transfer movement, which allows complete patient access for on-going resuscitation.

Utilising linear slot scanning radiography (LSSR) and several modifications to the imaging chain, the system achieves an extremely low emitted and scattered X-ray dose [11]. The digital radiation dose relative to conventional X-ray dose varies from 72% (chest) to 2% (pelvis), with a simple average of 6% [11–13]. The radiation skin-entry dose averages 36 mrem (range 18 to 67) compared with a conventional dose of 591 mrem (range 20 to 2280) [14]. Effective doses are between 9% and 75% of the United Nations Scientific Committee Report on the Effects of Ionizing Radiation Doses for Standard Examinations [15].

3. Results: The Johannesburg Trauma Protocol

Previous studies have shown that this hospital admits approximately 16,356 trauma patients each year, which is an average of more than 44 per day. 51% of the cases occur over weekends, between Friday and Sunday. Of these, those seen between 18h00 and 08h00 far exceed those seen during “working” hours [2]. This is consistent with studies in other parts of the country [1, 3]. Approximately 1 in 20 patients sustain multiple injuries, and 60% are classified as serious, severe, or critical [2].

The hospital has had an LS installed since 2009, which is situated directly in the resuscitation area, on the pathway between the ambulance offloading area and casualty. Figure 2 illustrates the trauma protocol in place at CMJAH, which has been developed since the installation of this machine.

The chart shows how all casualty patients presenting to the ED, apart from those with a severely compromised airway, are scanned with the LS to obtain a full-body radiograph. ATLS and resuscitation are continued for P1 and P2 patients after this X-ray triage process. Less serious patients are discharged or rerouted to lower-priority casualty waiting areas.

4. Case Study: High Trauma Workload

To illustrate the use of Lodox as a triage tool, as presented in the trauma protocol of Figure 2, we present an example of the typical trauma load faced on a Saturday shift (7 am–7 pm). The staff on duty were one consultant, three doctors, a registrar, an intern, and seven nurses.

During this 24-hour period, 63 patients presented to the emergency department. On arrival, every patient received a full-body LS X-ray scan in the anteroposterior (AP) orientation. This image was used to triage patients into resuscitation (resus) bays, cubicles, and casualty/outpatient wards for treatment and discharge home. Of the 63 patients seen, 28 were classified as Priority 1 (P1) patients and taken to resus.

Table 1 shows the numbers of patients with each kind of injury. Fractures and lacerations were the most common causes for ED arrival. It is notable that stab wounds were the third most common causes of injury with a total of 8 victims. Although the cause for each patient’s injury was not always noted, it was recorded that 22 patients were the victims of motor vehicle accidents (MVAs). Whilst no “mini” mass disasters, such as minibus taxi crashes, occurred on this day, there were four occasions when 2 patients arrived simultaneously, with at least one being of P1 level. Simple averaging shows that a patient arrived at the ED every 22.8 minutes. However, the spread was not even; for instance, in the hour between 3 am and 4 am, 8 patients (4 P1) arrived at the ED.

Of the 28 P1 patients, 16 were eventually discharged home. During treatment, 18 were referred for follow-up CT imaging, 3 to orthopaedics, 1 to plastics, and 4 to other hospital departments. One patient was referred to another clinic, and 1 was not documented. All of the patients survived. Although Lodox X-ray scanning was performed within the first few
Table 1: The mechanisms of injury of the 63 patients presenting at the ED in a 24-hour period.

<table>
<thead>
<tr>
<th>Mechanism of injury</th>
<th>P1 patients (number)</th>
<th>Non-P1 patients (number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture/s</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Laceration</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Stab</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Soft tissue injury</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Eye/orbital injury</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Head injury</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Degloving injury</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Bite (human and dog)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Abrasion</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Gunshot wound</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Unrecorded</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>28</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

minutes at the ED, the mean time between arrival and final discharge from the ED was lengthy at 12 hours and 51 minutes (minimum 1 hour and 20 minutes and maximum 72 hours). 39 patients were referred to radiology for further plain X-rays.

Figure 3 shows two full-body X-ray images of patients treated during this 24-hour shift.

5. Discussion

With death rates of more than 60,000 per year and one of the highest rates of traumatic death in the world, trauma is at epidemic levels in South Africa [16]. What this means “on the ground” in emergency departments countrywide is a situation where demand exceeds capacity. In this situation, it is essential to be able to prioritise patients based on the severity of trauma to ensure that the limited resources available are used in the best possible way. In short, this means a method of accurate triaging [17].

Undertriage is defined as the underestimation of the severity of an illness or injury, resulting in a patient receiving lower levels of treatment than required. Historically, acceptable undertriage rates have been set at 5% or less. Conversely, overtriage is the overestimation of the severity of an illness or injury. Acceptable overtriage rates are much higher, typically up to 50% in an effort to avoid undertriage. However, the impact of a high overtriage rate is a high rate of resource misallocation, with the potential that a truly critical patient is compromised due to overtriage of a previous patient [18].

The provision of X-ray information early on in the resuscitation process has not been previously explored as
a method of triage for mass disaster, “minimass disaster,” or high volume trauma scenarios. This is because X-ray imaging is often not available within resuscitation, cannot be performed on unstable or critical patients, takes a relatively lengthy time to perform (8–48 minutes [10]), and must be performed with caution due to radiation dose considerations [19]. This potentially limits its use in classifying patients early in the resuscitation process. Traditionally, X-ray information is obtained as an adjunct to the primary survey after the ABCDE process has been completed [20].

The LS system provides full-body X-rays in 13 seconds. Furthermore, it emits a very low level of scattered radiation, which means it can be situated directly within the resuscitation area without putting staff or patients at risk [10]. It therefore follows that it has the potential to be used differently to other radiation equipment within the trauma protocol. In this hospital, the X-ray information is provided as one of the first steps on arrival at the ED and, together with clinical decision-making tools, used to determine severity of injury and therefore further allocation of limited trauma resources.

Boffard et al. compared trauma-imaging times with the LS versus conventional imaging and found a reduction of 10.4 minutes (LS 29% faster) [9]. Exadaktylos et al. recorded a much higher improvement of 86.4% faster when LS was used for trauma imaging (19.2 minutes faster) [10]. These results indicate that, together with a unique physical positioning, the speed of image acquisition could prove to be useful in a situation where rapid, accurate triage is required. In this case study, imaging times were not recorded, only the overall time before discharge from the ED, which remained very lengthy when compared to previously reported numbers (an average of over 12 hours compared to 70.73 minutes) [9]. This indicates that the value of LS in this setting is as a tool to best allocate resources rather than a means to speed up trauma treatment.

It has also been previously reported that LS imaging is much safer than conventional imaging, with doses of ionising radiation being reduced by up to 94% [11–13]. This means that the radiation exposure concerns, which might limit the use of conventional X-ray systems as a triage tool, are possibly not as applicable to LS imaging. However, most patients with orthopaedic injury were referred for further X-ray imaging after initial triage and treatment (39 patients). This indicates that conventional X-ray is still preferred for focal X-rays of injured extremities, so the LS does not replace these X-rays. In this hospital, the main reason for this is the lack of ability to print hard copy films of LS images, which the orthopaedic surgeons require before operating. Nevertheless, any exposure to ionising radiation should be viewed with caution, and the LS is no exception.

The traditional ATLS response dictates that, on arrival, the primary survey, consisting of the “ABCDE” steps of airway maintenance, breathing and ventilation, circulation, disability/neurological assessment, and exposure/environmental control, is first performed. Following that, the secondary survey, involving a head-to-toe evaluation plus history, is performed. X-ray imaging can be selected as an adjunct to the primary and/or secondary surveys, but is never usually performed before the “ABCDE” evaluation is started [20].

Two groups have previously reported on modified trauma imaging protocols using the LS. Pitcher et al. studied the implementation of LS at the Red Cross Children’s Hospital in Cape Town, South Africa [21]. They found that the system increases efficiency in the case of paediatric polytrauma and accordingly modified their protocol from a standard CR polytrauma series (lateral cervical spine, supine chest, AP pelvis, and localised imaging of additional areas of clinical suspicion for bony injury) to an LS full-body AP X-ray, an LS lateral cervical spine, and an LS lateral view of any further areas of suspicion. They note that this time-saving protocol facilitates more comprehensive and efficient triaging, particularly in cases of mass casualty.

Evangelopoulos et al. presented their modified trauma protocol—The Bernese Modified ATLS Protocol—placing Lodox, together with ultrasound, as low-dose imaging adjuncts to the primary survey, allowing for a "better understanding of patients’ injury patterns" [22]. They also comment that this combination of imaging, before beginning the secondary survey, may allow for a reduction in the number of CT scans required. Whilst, in this setting, reduction of CTs is suggested as a dose and cost saving to the patient (and hospital), in a developing world and/or mass casualty situation it could also be viewed as optimising resource utilisation.
The modified trauma protocol presented in this report shows the LS situated at the beginning of the ED path, before the ATLS response has begun. Its primary role is to act as a very specific triaging tool, allowing the small medical team and limited ED resources to be directed as best as possible. It does, however, also play the part of X-ray imaging adjunct to the primary survey, as in the Red Cross and Bernese Trauma Protocols. Other tools could be used to further streamline this process. The SATS also targets the triaging process as the key to streamlining trauma response. It, too, has been developed in response to the chronically high trauma rates in South Africa. Specifically for the South African setting and taking into account the staff and resource imbalances, it allows trained nursing staff to perform triage based on a four-level colour-coded system of severity [6]. The use of SATS has been shown to improve under- and overtriage rates when compared to the internationally used modified early warning score (MEWS). On average, SATS improved undertriage rates by 10.8% and overtriage rates by 4% [8]. Whilst it has been effectively applied in other developing world settings, it is unfortunate that this system is formally in place in only one province in the country, hampering its benefit to major Level 1 Trauma Centres [17]. No studies have been performed on the effect of LS imaging on under- and overtriage rates, and this would be required before definite conclusions on its role in triage can be made.

Many countries and organisations have put thought into developing response, triage, and treatment protocols for disaster preparedness since the advent of the “War on Terror” in 2001 [23]. In the developed world, this means practised responses for once-off situations of attack or disaster [23]. However, in the developing world, the number of patients being treated versus the resources is a constant and ongoing challenge faced by emergency medicine practitioners. For instance, the (deservedly) much-lauded medical response to the Boston Marathon bombings “mass disaster” meant that Boston’s busiest trauma centre (Brigham and Women’s Hospital) was “flooded” with 31 patients in a day. This is less than half the amount reported here, on a fairly typical Saturday in a South African Level 1 trauma centre [1, 2]. This indicates the need for relevant solutions to the specific trauma problem faced in South Africa and other developing countries.

6. Conclusion

Effective and accurate triage is the key to dealing with the resource versus needs imbalance in the developing world. The trauma workflow and case study presented in this paper indicate the possibility that high-speed, low-dose, and full-body X-ray (Lodox/Statscan) imaging, when used on entry to the ED, could be an efficient and accurate method of triage in these underresourced situations.

Conflict of Interests

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References


Prehospital Emergency Ultrasound: A Review of Current Clinical Applications, Challenges, and Future Implications

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Imaging modalities in the prehospital setting are helpful in the evaluation and management of time-sensitive emergency conditions. Ultrasound is the main modality that has been applied by emergency medical services (EMS) providers in the field. This paper examines the clinical applications of ultrasound in the prehospital setting. Specific focus is on applications that provide essential information to guide triage and management of critical patients. Challenges of this modality are also described in terms of cost impact on EMS agencies, provider training, and skill maintenance in addition to challenges related to the technical aspect of ultrasound.

1. Introduction

Emergency ultrasound performed by nonradiologists has been widely adopted in most emergency departments (EDs) across the United States (US) and the world with a continuously growing list of diagnostic and therapeutic applications [1]. This technology enables emergency physicians to answer focused clinical questions at the bedside, which would translate into faster and more accurate diagnosis and care of patients presenting with time-sensitive emergency conditions. Better outcomes have been reported with the use of emergency ultrasound [2].

The use of this technology in the prehospital setting is increasing with reports of physicians and nonphysicians performing diagnostic and therapeutic interventions in different emergency medical services (EMS) systems across Europe and the United States [3]. This was facilitated by the portability of modern ultrasound machines that have small, lightweight, and durable designs and that deliver high-quality and high-resolution imaging.

Like any other intervention, the addition of ultrasound machines to the armamentarium of prehospital providers raises several questions in terms of potential clinical applications, feasibility, training requirements, cost, and more importantly its impact on the care process and on patient outcome. The type of EMS system that is in place, whether it follows the Anglo-American model or the Franco-German one, is an important factor to consider when discussing any prehospital intervention including prehospital ultrasound [4].

This paper reviews the available literature about current applications of ultrasound use in the prehospital setting and discusses challenges, limitations, and potentials of prehospital emergency ultrasound. The evidence presented is specific to emergency ultrasound performed in the prehospital setting and does not reflect the available evidence for all the medical indications and emergency or critical medicine recommendations for ultrasound use in the ED or in-hospital.

2. Clinical Applications of Prehospital Ultrasound

Clinically relevant applications of emergency ultrasound in the prehospital setting fall into two broad categories: diagnostic and therapeutic. Most of the published literature of ultrasound use in the prehospital setting falls into the diagnostic category.
Regardless of the type of EMS systems in terms of level of available prehospital providers, diagnostic applications, which can be easily learnt, can offer crucial information needed to guide the management of severely ill trauma and medical patients in the field and to help triage these patients to appropriate hospital destinations [5]. Therapeutic applications, on the other hand, are highly dependent on the sonographer’s skill level or type of prehospital provider.

2.1. Trauma Care. In EMS systems with regionalized trauma care and field triage guidelines [6] earlier detection of pericardial effusions in patients with penetrating thoracic trauma or of intra-abdominal free fluid (Figure 1) in patients with blunt trauma can be very helpful in helping providers decide on the method of transport and trauma center level destination.

In one prospective multicenter study of 202 trauma patients, prehospital focused abdominal sonography for trauma (PFAST) performed by emergency physicians and paramedics at the trauma scene had much higher sensitivity, specificity, and accuracy of detecting hemoperitoneum when compared to regular physical examination (93%, 99%, and 99%, resp., compared with 93%, 52%, and 57%) [8]. The PFAST examination time had a mean of 2–4 min (SD 0–8) and was completed 35 (SD 13) min prior to a regular emergency department (ED) FAST. A change in prehospital management, mainly fluid resuscitation, was reported in up to 21% of patients when PFAST was used. PFAST findings also influenced the decision making process regarding the mode of transport (ground versus helicopter) and the choice of hospital destination in up to one-third of patients [7]. In another study by Heegaard et al. trained paramedics carefully supervised by ultrasound-trained physicians detected free intraperitoneal or pericardial fluid in 71% of patients on whom FAST was performed in the prehospital field with excellent accuracy (100% proportion of agreement with physician overreader) [8]. Another published report also explored the potential of prehospital ultrasound to help rule out hemoperitoneum or hemopericardium in a trauma patient with PEA arrest [9].

Prehospital ultrasound use in trauma patients with suspected pneumothorax may be useful in preventing harm from unnecessary field intervention such as needle thoracostomy. When thoracic ultrasound was used to detect lung sliding sign (pleural sliding concomitant with insufflations or respirations in the absence of a pneumothorax) in the emergency department in patients after prehospital needle thoracostomy, 15 out of 57 (26%) trauma patients “appeared not to have had a pneumothorax originally nor to have had one induced by the needle thoracostomy” [10]. Harm to patients could potentially be avoided by the use of ultrasound prior to performing invasive procedures en route to hospital.

Despite all the previous reports documenting improvement in diagnostic accuracy, a recent systematic review evaluating whether prehospital ultrasound improves treatment of trauma patients found that there is a lack of evidence regarding improved treatment [11].

2.2. Medical Care. Cardiac arrest and shock or prearrest conditions are other EMS priority conditions where prehospital ultrasound adds value to patient management and outcomes.

In one prospective observational study of 230 patients in peri-resuscitation state (profound hypotension and/or severe dyspnea/tachypnea) or actively undergoing cardiopulmonary resuscitation (CPR), focused echocardiographic evaluation in life support (FEEL) performed in the prehospital setting altered the diagnosis and management in a significant number of patients [12]. The FEEL protocol was implemented by emergency physicians during an advanced-life-support (ALS-) confirmed interruption of CPR of fewer than 10 s noting the following features: cardiac motion (present or absent), ventricular function (normal, moderately impaired, severely impaired, or absent), right ventricular dilatation, or pericardial collection [12]. In patients undergoing CPR, ultrasound use demonstrated cardiac wall motion in 13 out of 37 patients (35%) whose initial ECG diagnosis was asystole, which correlated with increased survival to hospital admission [12]. In addition to that, ultrasound helped, through detection of cardiac motion, differentiate between true PEA (TPEA or electromechanical dissociation) and pseudo-PEA (PPEA or coordinated electrical activity with no palpable pulse). PPEA was also associated with increased survival to hospital admission when compared with TPEA [12]. In patients in a peri-resuscitation state, ultrasound improved the diagnostic accuracy for potential diagnoses of tamponade, profound hypovolemia, myocardial insufficiency (severe left and/or right ventricular dysfunction), or thromboembolism (pulmonary or cardiac). These findings warranted a change in management in 89% of patients in the CPR group and 66% of patients in the peri-resuscitation group [12]. EMS systems with prehospital protocols that use asystole or PEA as criteria for field termination of the resuscitation can therefore benefit from adding ultrasound to such protocols [13, 14]. More evidence is, however, needed to rely solely on ultrasound findings to halt resuscitative efforts in patients with cardiac arrest. An observational study by Aichinger et al. examined the utility of prehospital emergency echocardiography in predicting outcomes in the management of cardiac arrest patients. Forty patients were included in their study. “Cardiac movement was associated with survival, and cardiac standstill...
at any time during CPR resulted in a positive predictive value of 97.1% for death at the scene" [15]. Their results did not support the use of prehospital ultrasound findings as the sole predictor of outcomes in cardiac arrest patients. A more recent systematic review by Blyth et al. examining whether detection of cardiac contractility on bedside echocardiography predicts return of spontaneous circulation (ROSC) during cardiac arrest reached the same conclusion [16].

Prehospital ultrasound diagnostic applications have also been reported in patients with acute undifferentiated dyspnea. Prehospital ultrasound improves the accuracy of diagnosing pulmonary edema as the cause of acute dyspnea. In a prospective cohort study of 218 patients presenting with acute dyspnea (heart failure or COPD/asthma related), ultrasound performed by prehospital physicians in less than one minute, was found to be the strongest predictor for the diagnosis of heart failure in the prehospital setting [17]. Ultrasound was superior to both point-of-care N-terminal probrain natriuretic peptide testing and to clinical examination using Boston modified criteria [17, 18]. Seeing B-lines (sonographic artifacts caused by the interaction of water-rich structures and air) on the initial lung ultrasound had 100% sensitivity, 95% specificity, 100% negative predictive value, and 96% positive predictive value for the diagnosis of heart failure in the prehospital setting [17, 19].

Zechner et al. reported a similar benefit of improved accuracy in diagnosing the cause of acute dyspnea in two patients when prehospital ultrasound was used. This translated into improved clinical outcome when the treatment provided was based on the prehospital ultrasound findings [20].

Prehospital ultrasound was also reported to be useful in patients with unexplained hemodynamic instability where it helps differentiate between cardiac and noncardiac etiologies of shock. Adding ultrasound to prehospital shock management can help rule out the presence of life-threatening conditions such as clinically significant pericardial effusion or abdominal aortic aneurysms [12, 21, 22]. Bourrier et al. also discussed the potential of prehospital ultrasound to detect massive pulmonary emboli (PE) in patients with refractory shock and when high clinical suspicion for PE exists [12, 23].

2.3. Airway Management. Another new diagnostic application of prehospital ultrasound consists of confirming endotracheal tube (ETT) placement through detection of the lung sliding sign [24]. Advanced airway management using ETT placement is commonly performed in EMS systems that employ ALS providers (paramedics) or physicians. End tidal CO₂ capnography is the gold standard method for ETT correct placement confirmation. This method has some limitations in specific situations such as cardiac arrest, low cardiac output, acute pulmonary embolism, and hypothermia [25, 26]. Ultrasound offers prehospital providers an alternative method for ETT confirmation for recognizing tube displacement or differentiating between main tracheal intubation and right mainstem intubation. This technique is, however, operator dependent and is limited in the setting of pneumothorax or subcutaneous emphysema [24].

Most of the previously described diagnostic applications would help prehospital providers establish a more accurate diagnosis and guide patient management or triage to appropriate hospital destinations. On the other hand, therapeutic applications of ultrasound in the prehospital setting are highly dependent on the skill level and the scope of practice of the operator or prehospital provider. Applications such as ultrasound-guided pericardiocentesis have been described but mainly in systems with physicians working in the prehospital setting [12].

3. Challenges of Prehospital Ultrasound

Despite the wide range of applications for ultrasound in the prehospital setting, the adoption of this modality has been slow for several factors including, but not limited to, portability, cost, training and technical expertise of operators, and time limitations. Several studies with new handheld and portable models of ultrasound machines have demonstrated that ultrasound use is possible in most prehospital settings including land ambulances and helicopter EMS [5, 12, 27–29].

Time limitation is another challenge that is often cited as a reason for not using ultrasound. Lack of enough time was the main reason for not using thoracic ultrasound in one study examining the feasibility of thoracic ultrasound by HEMS [30]. Other studies have shown, however, that most focused ultrasound applications can be completed in less than 3 minutes without delaying the management or increasing on scene time [17, 28]. Even for the most time-sensitive conditions such as cardiac arrest, ALS compliant protocols of ultrasound use minimizing compression interruption time have been described and can be implemented in the prehospital setting [12, 31].

Training and technical expertise of providers are another challenge for ultrasound adoption in the prehospital setting. This limitation is pertinent only to EMS systems that use providers other than physicians to staff their ambulances. Physicians working in the prehospital setting would have to undergo the same training as other nonradiologist physicians who have ultrasound privileges and who use ultrasound in the ED or other settings (intensive care units, operating rooms). In EMS systems that use nonphysician providers such as the US and UK EMS systems, ultrasound is considered an advanced skill that is usually limited to advanced level providers such as paramedics. Ultrasound applications and more specifically therapeutic interventions are also closely tied to the scope of practice and skill levels of these nonphysician providers.

Several studies have demonstrated that paramedics can easily acquire ultrasound skill with training duration varying from one hour and 15 minutes to two days depending on the type of diagnostic ultrasound application learned [7, 30, 32]. In one study by Roline et al. assessing the feasibility of thoracic ultrasound by HEMS flight crew, providers received a training in thoracic ultrasound consisting of a video of 15-minute duration, followed by hands-on session for 60 minutes to detect lung sliding sign. Forty-one patients underwent thoracic ultrasound with 54% of the images being
considered to be of good quality. There was substantial agreement between the flight crew’s interpretation and the expert reviewer’s interpretation of the images (Cohen kappa statistic of 0.67 (95% CI, 0.44–0.90)) [30]. In another study by Chin et al., twenty emergency medical technicians paramedics with no prior ultrasonography training underwent training to acquire and recognize ultrasound images for several life-threatening conditions using the Prehospital Assessment with UltraSound for Emergencies (PAUSE) protocol [32]. The training consisted of 1 h lecture on the basics of ultrasonography, the PAUSE protocol, image acquisition, and basic image interpretation for the heart and lungs followed by one hour of hands-on session. When tested in a classroom setting, “paramedics obtained adequate images that could be used in evaluation of pneumothoraces, pericardial effusion, and cardiac standstill and correctly evaluated ultrasound video of those conditions” [32]. Higher success was documented for acquiring images to check for pneumothorax than for pericardial effusion or cardiac standstill [32].

In a different study by Heegaard et al. paramedics underwent 6 hours of structured ultrasound training and were able to adequately obtain and interpret prehospital FAST and abdominal aortic (AA) ultrasound images with 100% interpretation agreement with physician overreader [8]. Other published reports also support the successful training of paramedics in ultrasound use in the prehospital setting [33].

Initial ultrasound skill acquisition by paramedics is therefore possible with relatively short training courses. Ultrasound skill maintenance like any other skill requires practice and good quality management programs with physician oversight.

One way to overcome the potential challenge of training prehospital providers to acquire and interpret ultrasound images is through the use of telesonography. Transmitting ultrasound images by different modalities from scene to ED is an effective tool that can be implemented in EMS systems that lack advanced level providers or in rural EMS systems for expert review of images and interpretation. Novel techniques of telesonography using cellular or satellite networks allow for the successful transmission of real-time ultrasound images from the prehospital setting to the ED without affecting the quality of the images [34].

The cost impact on EMS agencies introducing ultrasound into the prehospital setting has not been formally assessed. The new hand held ultrasound machines cost around US$ 9000. This is a significant cost for most systems especially when considering the number of units to be deployed in order to cover a large proportion of patients with time-sensitive emergency conditions on whom ultrasound use may reduce morbidity and improve outcomes.

4. Future Implications

Acute ischemic stroke is another EMS priority condition that is time sensitive and where ultrasound is showing promise. In a recent study by Schlachetzki et al. 102 patients with acute stroke symptoms underwent prehospital transcranial color-coded sonography (TCCS) assessments [35]. Prehospital diagnosis of middle cerebral artery (MCA) occlusion using ultrasound was highly sensitive (90% (95% CI 55.5–99.75%)) and specific 98% (95% CI 92.89–99.97%) when compared to standard stroke imaging (CTA or MRA). The average time for completion of the ultrasound study by a neurologist was 5.6 min (SD 2.2). Field diagnosis was made early in the prehospital care phase (mean time to arrival of patient of 12.3 min (SD 7.09)) [35]. This study required, however, experienced neurologists who are skilled in neurosonography to perform the procedure and reach the diagnosis in a timely fashion. Future research regarding early ultrasound diagnosis of ischemic stroke in the prehospital setting should impact stroke management and improve on time to thrombolysis which would translate into better neurologic outcomes of stroke affected patients [36].

Prehospital ultrasound might have limited applications in the prehospital field that constitutes only one phase of emergency care. The scope of applications of emergency ultrasound is, however, much broader for emergency cases in other settings (ED, in-hospital, or remote areas). Added focus on three areas would increase the potential for ultrasound use in the prehospital field. First, enhancing the technology of telesonography for real-time assistance with interpretation of ultrasound images is important for EMS systems that lack advanced level providers. Second, developing effective ultrasound training programs for different level providers similar to the RUSH exam used by emergency physicians [37] is needed for timely evaluation and management of the critically ill in the field. Last but not least, dedicated research focusing on the benefit of performing existing clinical applications early in the field (abdominal aortic aneurysms in patients with abdominal pain) would support the use of prehospital ultrasound and potentially improve patient outcomes.

5. Conclusion

Prehospital emergency ultrasound has many clinical applications that would reduce morbidity and improve outcomes of patients with life-threatening emergency conditions. This imaging modality improves diagnostic accuracy and provides crucial information to prehospital providers to guide management and help triage patients to appropriate destinations. Training requirements and time limitations are the main challenges to prehospital ultrasound utilization. Structured training of nonphysician prehospital providers is needed to provide them with adequate ultrasound skill acquisition and maintenance. The potential for use of this modality in the prehospital setting is great; however, outcome research is needed to provide stronger evidence on its clinical impact on patient outcome.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.
References


Research Article

Focused Assessment with Sonography in Trauma and Abdominal Computed Tomography Utilization in Adult Trauma Patients: Trends over the Last Decade

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Objective. We sought to describe the trend in abdominal CT use in adult trauma patients after a point-of-care emergency ultrasound program was introduced. We hypothesized that abdominal CT use would decrease as FAST use increased. Methods. We performed a retrospective study of 19940 consecutive trauma patients over the age of 18 admitted to our level one trauma center from 2002 through 2011. Data was collected retrospectively and recorded in a trauma registry. We plotted the rate of FAST and abdominal CT utilization over time. Head CT was used as a surrogate for overall CT utilization rates during the study period. Results. Use of FAST increased by an average of 2.3% (95% CI 2.1 to 2.5, \( P < 0.01 \)) while abdominal CT use decreased by the same rate annually. The percentage of patients who received FAST as the sole imaging modality for the abdomen rose from 2.0% to 21.9% while those who only received an abdominal CT dropped from 21.7% to 2.3%.

Conclusions. Abdominal CT use in our cohort declined while FAST utilization grew in the last decade. The rising use of FAST may have played a role in the reduction of abdominal CT performed as decline in CT utilization appears contrary to overall trends.

1. Introduction

There has been a doubling of patient exposure to ionizing radiation in the last two decades in the United States. This increase is largely attributed to an explosive rise in the use of computed tomography (CT) [1]. Approximately, more than 62 million CT scans are currently obtained annually in the United States, compared to 3 million in 1980 [2]. Specifically, 18.3 million abdominal CT’s are performed in the United States in 2007 [3]. Thus, in addition to increasing concerns about the rising cost of diagnostic imaging, there is growing and justifiable concern regarding health risks of radiation exposure [2–6]. Despite a frequently favorable benefit-to-risk ratio for the use of CT in symptomatic patients, increasing literature suggests an overuse of CT and questions its yield in specific contexts, including the evaluation of blunt trauma [7–12]. While much critique is based on pediatric data, the highest public health impact of reducing CT use may be in adults, specifically in reducing chest and abdominal scans in adult trauma patients aged 35–54 [3]. Thus, the Food and Drug Administration has recently proposed a national initiative to reduce radiation exposure from unnecessary imaging [13]. Concomitantly, the use of ultrasound in emergency medicine has blossomed [14–18]. Benefits of emergency bedside ultrasound include lack of radiation exposure, ability to perform imaging in the safety of the resuscitation room or in resource limited settings, and its ready repeatability as the patient’s condition evolves.

Previous literature suggests that the establishment of an emergency ultrasound program, at least initially, may result in increased ordering of other diagnostic imaging, specifically formal consultative ultrasound [19–21]. However,
as a program matures, the use of consultative ultrasound decreases dramatically [21]. In the intensive care setting, the use of bedside lung ultrasound has been shown to reduce the number of chest X-rays and chest CTs performed [22]. Nevertheless, definitive evidence correlating the use of ultrasound with the use of CT in trauma is lacking.

In our study, we sought to describe the trend in abdominal CT use in adult trauma patients before and after the introduction of a point-of-care emergency ultrasound program established at our hospital in 2004. Consequently, use of Focused Assessment with Sonography in Trauma (FAST) is now a routine at our institution. We hypothesized that there would be a rise in the number of FAST exams performed during our study period, and an inverse correlation between the number of FAST exams and the use of abdominal CT.

2. Materials and Methods

We performed a retrospective study of 19940 consecutive adult trauma patients age 18 or older admitted to our level one trauma center after ED evaluation from 2002 through 2011. Data were extracted from our trauma registry. Data points included age, gender, trauma mechanism, arrival time and date, length of stay in the emergency department, chief complaint, initial systolic blood pressure, Glasgow Coma Scale, head CT, FAST and abdominal CT results, injury severity score (ISS), ED disposition, and mortality rates. Data was collected and entered into the trauma registry retrospectively through review of the medical record by trained research assistants blinded to the objectives of this study. FAST results were extracted from the emergency department physician and surgical consult documentation. Monitoring of our research assistance or assessment of inter-rater reliability amongst them was not performed. Our institutional Investigations Review Board approved the study.

FAST exams in our department were performed at the clinician’s discretion without knowledge of our study and interpreted by emergency medicine and trauma surgery residents supervised by their respective attendings for the purpose of detecting intra-abdominal free fluid. A positive FAST was defined as the presence of any free fluid seen in the abdomen, most typically in the dependent areas of the peritoneum such as in Morison’s Pouch, in the perisplenic space, beneath the diaphragm and/or in the rectovesicular recess. As we were interested in abdominal CT utilization, the cardiac view was considered irrelevant. A positive abdominal CT was defined by the trauma registry as hemoperitoneum, retroperitoneal, and pelvic hematoma, or any significant injury to abdominal organs or bowel. Isolated injury to bony structures was not included as a positive CT finding. In our cohort, the term “abdominal CT” was synonymous with abdominal and pelvic CT.

We plotted the percentage of patients in whom an abdominal CT and FAST were performed by year. We used head CT rate as control as a marker for overall CT utilization rates during the study period because as the use of decision support rules for head CT utilization in trauma patients became widespread, the rate of head CT ordering would be seen as stabilizing over this period. By contrast, there have been no such rules for abdominal or chest CT utilization in trauma patients, and therefore we anticipate a decline in head CT utilization rate over this time period relative to the rate of abdominal CT utilization. The trend of average FAST and abdominal CT rates per year over the study period was calculated by univariate regression. We also observed the percent of negative abdominal CTs during the study period.

All confidence intervals and P values were generated through statistical analysis using STATA (STATA Corp, College Station, TX). We used Student’s t-test for mean values of normally distributed continuous/quasicontinuous variables, ranked-sum (Mann-Whitney) test for non-normally distributed variables, and Pearson’s Chi-squared test for percentage values to determine their statistical significance (P values). Multivariate logistic regression was used to control for changing clinical and demographic factors over time when assessing CT and FAST usage trends.

3. Results

19940 adult patients who were admitted to the trauma service during the study period were enrolled in our study. 474 (2.4%) of these patients were missing data on whether a FAST and/or abdominal CT was performed (187 were missing FAST data, 8 were missing abdominal CT data, and 279 were missing both) and therefore excluded from the analysis. Most (96%) of the excluded patients with missing data (433 out of 474 patients) were from 2002 because FAST and abdominal CT results were added to the registry after April, 2002. Demographic characteristics of patients with missing imaging data are outlined in Table 3. Thus, 19466 records with complete imaging data were included in the analysis. Of these, 11594 (59.6%) were male. The mechanism of injury was predominantly blunt (89.3%) rather than penetrating (10.5%). Table 1 shows the patient demographics and the imaging performed per year. Patients who underwent FAST were on average younger (43.4 versus 59.0, P < 0.01), more likely to be male (70.9% versus 55.1%, P < 0.01), more likely to have higher median injury severity scores (ISS) (14 versus 9, P < 0.01), more likely to be admitted to the ICU (29.4% versus 9.0%, P < 0.01), more likely to go to the OR (19.1% versus 17.1%, P < 0.01), more likely to undergo abdominal CT (52.7% versus 11.7%, P < 0.01), more likely to have a positive result on abdominal CT (19.1% versus 12.3%, P < 0.01), and more likely to die (71.1% versus 4.2%, P < 0.01) when compared to patients who did not receive an FAST (Table 2).

In our study, 2904 patients received both FAST and abdominal CT. FAST had a sensitivity of 20.0% (CI 16.7–23.6%), specificity of 98.3% (CI 97.6–98.7%), positive likelihood ratio of 11.5, negative likelihood ratio of 0.81, PPV of 0.73, and NPV of 0.84 for predicting intra-abdominal injuries diagnosed on abdominal CT, the prevalence of which was 19.1% in this cohort.

Overall, the use of FAST increased by an average of 2.3% (95% CI 2.1 to 2.5, P < 0.01) per year while abdominal CT use decreased by an average of 2.3% (95% CI –2.5 to –2.0, P < 0.01) per year (Figure 1). Head CT use decreased by an average of 0.8% (95% CI –1.1 to –0.6, P < 0.01) per year. If the head CT utilization rate is used as a surrogate for the
Table 1: Patient demographics and imaging studies performed by year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of patients</th>
<th>Median age (years)</th>
<th>Mortality (%)</th>
<th>Median ISS</th>
<th>Dispo to OR (%)</th>
<th>Dispo to ICU (%)</th>
<th>Number of FAST</th>
<th>Percentage of FAST*</th>
<th>Number of abdominal CT</th>
<th>Percentage of abdominal CT*</th>
<th>Number of head CT</th>
<th>Percentage of head CT*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>1279</td>
<td>49.2</td>
<td>6.25</td>
<td>9</td>
<td>2.22</td>
<td>1.48</td>
<td>195</td>
<td>15.25</td>
<td>447</td>
<td>34.95</td>
<td>609</td>
<td>47.62</td>
</tr>
<tr>
<td>2003</td>
<td>1792</td>
<td>51.5</td>
<td>5.80</td>
<td>9</td>
<td>2.29</td>
<td>1.46</td>
<td>315</td>
<td>17.58</td>
<td>532</td>
<td>29.69</td>
<td>828</td>
<td>46.21</td>
</tr>
<tr>
<td>2004</td>
<td>1791</td>
<td>49.3</td>
<td>5.58</td>
<td>9</td>
<td>2.24</td>
<td>1.53</td>
<td>383</td>
<td>21.38</td>
<td>577</td>
<td>32.22</td>
<td>836</td>
<td>46.68</td>
</tr>
<tr>
<td>2005</td>
<td>1857</td>
<td>51.5</td>
<td>5.22</td>
<td>9</td>
<td>1.78</td>
<td>1.46</td>
<td>397</td>
<td>21.38</td>
<td>479</td>
<td>25.79</td>
<td>824</td>
<td>44.37</td>
</tr>
<tr>
<td>2006</td>
<td>1940</td>
<td>53.6</td>
<td>4.54</td>
<td>9</td>
<td>1.80</td>
<td>1.38</td>
<td>556</td>
<td>28.66</td>
<td>492</td>
<td>25.36</td>
<td>929</td>
<td>47.89</td>
</tr>
<tr>
<td>2007</td>
<td>2072</td>
<td>53.1</td>
<td>4.92</td>
<td>9</td>
<td>1.56</td>
<td>1.43</td>
<td>650</td>
<td>31.37</td>
<td>498</td>
<td>24.03</td>
<td>963</td>
<td>46.48</td>
</tr>
<tr>
<td>2008</td>
<td>2110</td>
<td>54.4</td>
<td>4.69</td>
<td>9</td>
<td>1.64</td>
<td>1.48</td>
<td>752</td>
<td>35.64</td>
<td>467</td>
<td>22.13</td>
<td>893</td>
<td>43.32</td>
</tr>
<tr>
<td>2009</td>
<td>2168</td>
<td>55.1</td>
<td>5.30</td>
<td>9</td>
<td>1.54</td>
<td>1.47</td>
<td>764</td>
<td>35.24</td>
<td>408</td>
<td>18.82</td>
<td>927</td>
<td>42.76</td>
</tr>
<tr>
<td>2010</td>
<td>2262</td>
<td>56.1</td>
<td>5.00</td>
<td>9</td>
<td>1.58</td>
<td>1.50</td>
<td>763</td>
<td>33.73</td>
<td>331</td>
<td>14.63</td>
<td>893</td>
<td>39.48</td>
</tr>
<tr>
<td>2011</td>
<td>2195</td>
<td>59.0</td>
<td>4.46</td>
<td>9</td>
<td>1.41</td>
<td>1.57</td>
<td>737</td>
<td>33.58</td>
<td>308</td>
<td>14.03</td>
<td>886</td>
<td>40.36</td>
</tr>
</tbody>
</table>

*Percentage of total patients who received the listed imaging test during their trauma evaluation in the ED.

Table 2: Comparison of demographics between patients who received an FAST and patients who did not.

<table>
<thead>
<tr>
<th></th>
<th>FAST not performed (N = 13954)</th>
<th>FAST performed (N = 5512)</th>
<th>All patients (N = 19466)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median age (years)</td>
<td>59.0</td>
<td>43.4</td>
<td>53.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>55.1</td>
<td>70.9</td>
<td>59.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Median ISS</td>
<td>9</td>
<td>14</td>
<td>9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Admitted to OR (%)</td>
<td>17.1</td>
<td>19.1</td>
<td>17.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Admitted to ICU (%)</td>
<td>9.0</td>
<td>29.4</td>
<td>14.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>4.21</td>
<td>7.08</td>
<td>5.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Abd CT performed (%)</td>
<td>11.7</td>
<td>52.7</td>
<td>23.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Abd CT positive (%)</td>
<td>12.3</td>
<td>19.1</td>
<td>16.6</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Table 3: Comparison of demographics characteristics between patients with complete imaging data and excluded patients.

<table>
<thead>
<tr>
<th></th>
<th>Included patients</th>
<th>Excluded patients</th>
<th>Entire cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>19466</td>
<td>474</td>
<td>19940</td>
</tr>
<tr>
<td>Median age (years)</td>
<td>53.7</td>
<td>46.0</td>
<td>53.5</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>59.6</td>
<td>60.5</td>
<td>59.6</td>
</tr>
<tr>
<td>Median ISS</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Admitted to OR (%)</td>
<td>17.7</td>
<td>16.5</td>
<td>17.7</td>
</tr>
<tr>
<td>Admitted to ICU (%)</td>
<td>14.8</td>
<td>13.5</td>
<td>14.7</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>5.0</td>
<td>6.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Overall trend of CT use independent of any potential impact of ultrasound, abdominal CT use still decreased by 1.5% annually. The percentage of patients in whom the result of abdominal CT was negative per year is shown in Figure 2. The percentage of patients who received FAST as the sole imaging modality for the abdomen during their trauma evaluation went from 2.0% to 21.9% while the percentage of patients who only received abdominal CT dropped from 21.7% to 2.3% over the last decade (Figure 3).

Almost half (2608 out of 5512 patients) who underwent FAST never required a CT at all. Of the 4539 patients who underwent abdominal CT, 2904 patients scanned with FAST
Figure 2: Percentage of patients in whom the result of the abdominal CT was negative by year.

Figure 3: Percentage of patients who received only one imaging modality of the abdomen in the ED by year.

were 6.8% less likely to have a negative CT result compared to 1635 patients in whom a FAST was not performed (80.9% versus 87.7%, \( P < 0.01 \)). Those 2752 patients with a negative FAST who then underwent CT were 3.8% less likely to have a negative abdominal CT result, compared to 1635 patients in whom an FAST was not performed (83.9% versus 87.7%, \( P < 0.01 \)). In effect, the FAST exam screened for those patients who were at increased probability for intra-abdominal injury.

4. Discussion

Initial evaluation of trauma in the last two decades has seen a shifting paradigm regarding favored methods to screen for intra-abdominal injury. Diagnostic peritoneal lavage (DPL) has been largely replaced by FAST. At our institution, there has been an almost four-fold increase in the number of FAST performed over the last 10 years with a concomitant decrease in DPL use [24, 25].

Concurrently, overall CT utilization in general has grown tremendously in the evaluation of emergency department patients. The challenge has always been to discover ways to decrease CT utilization without compromising patient outcome. Abdominal CT boasts a sensitivity of 99%-100% for free fluid and can detect other injuries that do not result in free intraperitoneal fluid [26–31]. FAST, however, has demonstrated efficacy in detecting intraperitoneal fluid only and has not been shown to identify the source of free fluid or diagnose bowel or solid organ injuries. With increasing pressures to maximize value in healthcare and reduce radiation exposure, there has been growing interest in optimizing imaging utilization strategies. In our retrospective study, we sought to further explore the use of FAST by clinicians to identify the “minimally sick” and “maximally sick” in order to inform more efficient diagnostic imaging utilization.

Other studies have shown that ultrasound-based clinical pathways in the evaluation of blunt abdominal trauma reduces the number of CT scans from 56% to 26% without increased risk to the patient when the FAST is negative [32]. The same investigators estimated a cost saving of $450,000 at their institution by replacing DPL with ultrasound in their clinical pathway [32]. Another study described a two-third reduction in trauma care costs for patients who underwent FAST compared to those who underwent CT scan or DPL [33]. These studies suggest that physicians proficient in performing FAST have decreased CT utilization and greater diagnostic efficiency without increased incidence of missed injuries despite previously published test characteristics of FAST and those from our own data [34]. This suggests that despite FAST’s known lack of sensitivity to rule out intra-abdominal injury, a certain cohort of patients can be managed using FAST without CT and that perhaps there are some injuries which are categorized as “missed” which may not be as clinically significant in terms of changing management or outcome. Better defining and standardizing which intra-abdominal injuries are essential to diagnose in the emergent trauma evaluation could help improve how FAST and other screening diagnostic tests are utilized. For instance, the clinical significance of a grade 1 liver laceration that requires no procedural intervention or change in disposition is still ardently debated [35]. Our study, which shows a correlation between increasing ultrasound use and a decrease in CT scan utilization for trauma patients, also suggests that FAST is being used as a stand-alone “rule out” test in certain cohort of patients. Until this practice is better understood and categorized, it is difficult to reconcile with published data.

Of note, the growth of FAST usage plateaued after 2008 which we hypothesized was due to providers having attained sufficient comfort level with its use in trauma after years of experience and the presence of a limit on the patients in whom FAST is considered clinically useful.

Interestingly, our results differed from the study by Inaba et al. that demonstrated a small but significant increase in CT utilization in trauma patients from 2002 to 2007; though the authors did not focus specifically on abdominal trauma and made no mention of ultrasound use [36]. Likewise, Roudsari et al. reported that abdominal CT use increased by 16% per
year between 1996–2006 in patients over 55 years of age whose primary traumatic mechanism was a fall [37]. This suggests that as in our setting a mature ultrasound program may have a role in decreasing CT diagnostic imaging in low risk patients despite the low sensitivity that has been reported in the literature.

Moreover, ultrasound in our study was also associated with higher rates of CT utilization (52.7% versus 11.7% \( P < 0.01 \)) in the patients with higher median ISS (14 versus 9, \( P < 0.01 \)) and those who were more likely to be admitted to the ICU (29.4% versus 9.0% \( P < 0.01 \)). This confirms our hypothesis that FAST is most useful in the extremes—in ruling in the sickest patients and focusing resources on them and in ruling out the least sick patients in whom injury is least suspected. Of the 4539 patients who underwent abdominal CT, 2904 patients scanned with FAST were 6.8% less likely to have a negative CT result compared to 1635 patients in whom a FAST was not performed (80.9% versus 87.7%, \( P < 0.01 \)). Those 2752 patients with a negative FAST who then underwent CT were 3.8% less likely to have a negative abdominal CT result, compared to 1635 patients in whom a FAST was not performed (83.9% versus 87.7%, \( P < 0.01 \)). This may demonstrate that a sicker cohort of patients undergoing FAST were screened by their providers and referred expeditiously to CT, which was higher yield after a FAST was performed.

Conversely, 2608 out of 5512 patients who underwent FAST never acquired a CT at all. Of these, 97 patients with a positive FAST who were hemodynamically unstable went directly to the OR. But for the vast majority (2461 patients), their negative FAST result appeared to have been sufficient to reassure the clinicians the absence of intra-abdominal injury. This is demonstrated by the fact that the percentage of patients who received FAST as the sole imaging modality for the abdomen during their trauma evaluation went from 2.0% to 21.9% while the percentage of patients who only received abdominal CT dropped from 21.7% to 2.3% over the last decade (Figure 3). This was surprising as the test characteristics for FAST were as noted above. This practice of “ruling out” intra-abdominal injury with FAST, which may be occurring with increasing frequency as ultrasound use became more prevalent, has been discouraged in the literature as the sensitivity of FAST, which confirmed to be low in our own cohort, has been demonstrated to be insufficient to rule out injury [38, 39].

But these studies were not done in trauma patients stratified by ISS. Patients with lower ISS may have a lower prevalence of clinically significant injury, and thus FAST scanning may be adequate to screen patients in such instances. This is an area that needs further study. Our results are consistent with the study by Branney et al. [32] which suggests that not only can FAST performance decrease diagnostic imaging but that it focuses resources on the management of the more severely injured patients. It also suggests, again, that diagnostic imaging strategies have to be developed in conjunction with mechanism of injury and ISS assessments and cannot be applied to “trauma patients” uniformly.

One point of interest from our analysis is that men were 15.8% (70.9% versus 55.1%, \( P < 0.01 \)) more likely to undergo an FAST (\( P < 0.01 \)) compared to women. We had initially attributed this to men having higher likelihood of severe injuries. While our data confirmed this, even after adjusting for ISS and ED disposition, men were still 11.1% (95% CI 9.9% to 12.4%, \( P < 0.01 \)) more likely to receive a FAST. It is unclear why this may be the case.

The strengths of our study include the substantial study size (19466 patients). Nevertheless, our study has several limitations. The study is retrospective and as such we cannot establish a causal effect of FAST on CT scan utilization. Rather, the trends we identified are correlations. Like any retrospective study on ultrasound, the reliance on documentation for FAST results can be problematic; and no quality assurance efforts were made to review and confirm FAST results. However, of the 19940 adult patients included in the database, only 466 patients (2.3%) were missing data regarding whether a FAST was performed. Although most (96%) of the excluded patients with missing data (453 out of 474 patients) were from 2002 as FAST and abdominal CT results were added to the registry after April, 2002, we decided to retain data from 2002 in our analysis as we wanted at least 2 years of data before our point-of-care emergency ultrasound program was started to assess its impact. While other patient demographics remained similar during our study period, the median age increased by a decade; possibly due to an aging population as our trauma activation and admission protocols have not changed. Older patients underwent fewer abdominal CT’s and FAST, likely due to the high instance of falls. For instance, 14.3% and 14.3% of >75 year-olds received an abdominal CT and FAST, respectively; while 28% and 33.6% of 35–55 year-olds received the same tests. As both FAST and CT were decreased as a function of age, the changing demographics over our study period likely affected FAST and CT equally. This was supported by univariate and multivariate logistic regression demonstrating that CT and FAST trends remained stable and statistically significant after controlling for age. We were unable to control for confounding factors such as changes in hospital system processes, ED and trauma attending practice patterns, and changing attitudes regarding the cost and radiation risk of CT that may have contributed to decreasing CT utilization. We attempted to mediate this limitation by using the head CT rate as a surrogate for the overall trend in CT use. While this practice has never been evaluated in other studies in the past, our choice to do so was based on the assumption that the Canadian Head CT Rules published in 2001 in theory should have impacted head CT utilization preferentially over abdominal CT use, for which evidence based practice guidelines are lacking [40]. Therefore, we believe that our findings are valid in that the trend to decrease abdominal CT utilization in our cohort is more marked. Our results differed from Lee et al., who reported a 60% increase in head CT use between 2003 and 2007 while the yield for positive results remained constant [41]. The difference is likely due to the fact that Lee’s study reported head CT use in all patient populations while our study involved only admitted trauma patients. Because our database included only admitted trauma patients, we can make no comment on trends in FAST and abdominal CT use in discharged patients, for whom we were unable to gather
data. While it is not the purpose of FAST to detect bowel or solid organ injuries, we noted an increasing trend in its use as a “rule out” test for intra-abdominal injury in selected low-risk patients. Although this has not been supported in the literature or by American College of Emergency Medicine clinical policies [42, 43], our aim was to simply describe this practice in hopes that future research can better delineate which population, if any, may benefit from an “FAST-only” algorithm without adverse outcomes.

5. Conclusions

From our analysis, we conclude that over the last decade in admitted adult trauma patients at our level 1 trauma center, the rate of FAST utilization has increased while abdominal CT use has declined. The rising use of FAST may have played a role in the reduction of abdominal CT use. Causation cannot be proven due to our inability to adjust for certain confounding factors that may have impacted the use of FAST and abdominal CT. Nevertheless, striking difference to the trends of increased CT utilization rates in the evaluation of emergency department patients in the United States is notable. Further study evaluating the impact of FAST results on the decision to order abdominal CT should be done, especially in patients at extreme ends of risk of intra-abdominal injury. Our study highlights the potential use of FAST as a screening diagnostic tool that could prevent unnecessary radiation exposure and minimize cost of care in a significant number of trauma patients.

Disclosure


Conflict of Interests

The authors declare that they have no conflict of interests.

References

Research Article

New Freedom through Medical Devices Based on the Global System for Mobile Communications: A Prospective Survey of 620 Users of the Swiss Limmex Emergency Wristwatch—An Original Study from Switzerland

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About 500,000 elderly people in Switzerland suffer a fall each year. Thus medical attention and help are essential for these people, who mostly live alone without a caregiver. Only 3% of people aged over 65 in Switzerland use an emergency system. Personal telehealth devices allow patients to receive enough information about the appropriate treatment, as well as followup with their doctors and reports of any emergency, in the absence of any caregiver. This increases their quality of life in a cost-effective fashion. “Limmex”—a new medical emergency watch—was launched in Switzerland in 2011 and has been a great commercial success. In this paper, we give a brief review of this watch technology, along with the results of a survey of 620 users conducted by the Department of Emergency Medicine in Bern.

1. Introduction

As a consequence of several demographic and social factors, the proportion of people living alone has been continuously increasing in recent decades. In urban areas such as the Bern region, about 50% of retired people live alone in single person households. The number of elderly people is increasing in Switzerland (1.4 million over 65 years), and for the great majority of these, it is very important to be able to live independently at home for as long as possible. Consequently, it is crucial that these elderly people should receive prompt medical attention and help when an emergency occurs. Studies have shown that when the elderly fall they are out of reach of the fixed-line network or a mobile phone. This is why it is important to wear an emergency system on the wrist or round the neck. Personal telehealth devices allow patients to receive enough information about the appropriate treatment, as well as followup with their doctors and reports of any emergency. This can take place in the absence of any caregiver and increases their quality of life in a cost-effective fashion [1–3]. We have found that only 37% of subjects thought that they would be found within 30 minutes of a serious emergency [4]. Despite these facts, only 3% of elderly individuals have access to a personal emergency system. In our opinion, the main reason for this is that current systems are bulky and indiscreet, which will somehow label and stigmatize their users as “sick.” In addition, some systems are complicated to install and are not fully portable. In 2011, the Swiss company “Limmex AG” and the Centre Suisse d’Electronique et de Microtechnique (Swiss Center for Electronics and Microtechnology) launched an “elegant” Swiss-made medical emergency watch (MEW) with an integrated emergency system function [5, 6]. MEW uses GSM-based technology packaged in a wristwatch. By pushing a button, the wearer can initiate multiple emergency calls and establish mobile communication with a preselected person, institution, or a search and rescue service (Figure I). MEW is waterproof against splashes and thus can be worn when taking a shower or bath. The watch has been a great commercial success, due to its simple, reliable, and easy-to-wear design. This paper will focus on the results of a survey of 620 MEW users conducted by the Department of Emergency Medicine in Bern.
2. Material and Methods

In collaboration with Limmex, the Department of Emergency Medicine of Bern University Hospital carried out an anonymous survey of MEW users \((n = 620)\). The survey was conducted 18 months after the market launch of the watch and aimed to collect the initial impressions of the users of the emergency watch. The survey included questions on demographics data, length of time since first wearing MEW, wearer satisfaction, impact of the device on their daily life, and the ease of use of the watch. Descriptive statistics were used to report sample characteristics.

3. Results

3.1. Demographic Data and Basic Information. The survey was sent to 1,350 persons in the medical/senior segment, with a response rate of 46% (620 persons). The mean age of the respondents was 81.8 years, 66% of whom were older than 70 (Figure 2). The majority of the survey respondents were women (81%). Eighty-five percent (85%) of the respondents answered that they live alone, and only 11% stated that they lived in a 2-person household. Most respondents thought that they would need MEW because they were “older people” (402 persons, 65%), followed by “single people” living alone (280 persons, 45%) (Figure 3). Twenty-seven percent (27%) of the respondents had been using their MEW for more than a year when they took the survey (Figure 4).

3.2. Satisfaction and Security. Ninety-four percent (506 persons, 94%) of the respondents stated that they were satisfied or very satisfied with MEW, while only 32 (6%) respondents stated that they were dissatisfied, and 82 (13%) respondents...
did not answer this question. Ninety-nine percent (565 persons, 99%) stated that they would recommend it to others. The majority of the users (532 persons, 98%) felt that they were more secure in their everyday life thanks to MEW.

3.3. Using MEW. When asked: “When do you use MEW and during which activities?” 96% (551 persons) answered that they thought that it is important to wear it at home; 89% (481 persons) also wore it during excursions, particularly when walking or hiking, followed by working around the house (307 persons, 83%). Ninety-three percent (479 persons, 93%) of MEW users wore the watch at night and 98% (539 persons) during the day.

3.4. Emergency Call Trigger. Ten percent (10%) of MEW wearers (55 persons) used it to call for help during an emergency. Forty-four percent of them (23 persons, 44%) had been wearing MEW for more than a year when an emergency occurred (Figure 5). The mean age of the wearer was then 81.6 years. The cause of the emergency was mostly a fall at home (38 persons, 69%).

4. Discussion

New research in many cultural settings is showing that older people prefer to be in their own homes and communities, even if that means living alone. This preference is reinforced by greater longevity, expanded social benefits, increased home ownership, more appropriate housing, and an emphasis in many nations on community care [7]. Researchers at Geneva and Lausanne universities have carried out a study analysing data on the demographic change, which was collected during the Swiss Census in 2000; this also supported this trend. They concluded that old people in Switzerland are living longer, healthier, and more independently, and that since 1990, the proportion of old people living in nursing homes has gone down [8]. Our study confirms this trend; the mean age of persons responding to the survey was 82 years, with the majority of them (85%) stating that they lived alone, and 45% of the respondents chose this reason for seeking an emergency personal system.

In our previous study, approximately 60% of those interviewed stated that they would feel safer if they had a device which enabled them to alarm a close person of their choice, the family doctor, or an emergency service in any medical emergency [4]. In our current survey, 98% of the users stated that they felt more secure in their everyday life thanks to MEW. Most of the users (94%) expressed their satisfaction with MEW, and 99% noted that they would recommend MEW to others. Similar results have been described by Mann et al., who surveyed 606 persons using a personal emergency response system (PERS); in their study, 76% of the participants expressed an enhanced feeling of security when using PERS [9]. During a 1-year follow-up period of 106 patients using PERS, Roush et al. found that there was a statistically significant decrease in hospital admissions per person and in time in hospital [10]. A study by Bernstein concluded that use of monitored PERS reduces mortality rates nearly fourfold and hospital utilization by 59% [11]. In the study of Mann et al., fear of falling was most often given as the reason for using a PERS in Mann et al. study [9]. In our study, a fall was found to be the main cause (69%) of emergency calls triggered using MEW.

Our study confirms the few studies published on PERS. The limitations were due to the fact that it is based on a survey, with only 10% of patients triggering an alarm call using MEW. The next step in confirming the reliability and ease of use of MEW will be to perform a follow-up study, looking more into the experience of users who actually triggered a call to the emergency services using their watch, together with their feedback about the product.

5. Conclusion

MEW has proved itself to be an innovative product; it provides a simple and reliable personal emergency system while delivering the accurate time with a well-designed Swiss-made watch. MEW was found to increase the feeling of safety and security among its users, with most of them expressing satisfaction. Doctors should introduce this system to suitable patients, particularly the elderly living alone. Patients can
be referred to the Red Cross, as they can offer a variety of emergency systems, recently including MEW watches, and can provide expert information. This can effectively help in avoiding falls followed by long periods of lying on the floor, which can have serious medical consequences.

**Conflict of Interests**

The authors disclose no affiliation with any organization with a financial interest, direct or indirect, in the subject matter or materials discussed in the paper (such as consultancies, employment, expert testimony, honoraria, lecturing fees, retainers, stock options, or ownership) that may affect the conduct or reporting of the work submitted.

**References**


Review Article

How Noninvasive Haemoglobin Measurement with Pulse CO-Oximetry Can Change Your Practice: An Expert Review

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Trauma related haemorrhagic anaemia is rarely diagnosed by physical examination alone but typically includes measurement of blood haemoglobin, one of the most frequently ordered laboratory tests [1, 2]. The need for resuscitation to achieve adequate tissue perfusion is established by the patient’s history, on-going bleeding, and clinical signs of hypovolemia. Haemoglobin and haematocrit measurements, the conventional means to confirm hypovolemia, are not always immediately available at the point-of-care and hemodynamic monitoring may not detect relevant blood loss. If treatment is delayed pending laboratory results or diagnostic studies, patient outcome can be affected [3–5]. In particularity in the emergency room, perioperative and critical care settings, rapid and on-going assessment of total haemoglobin is crucial, in order to quantify blood loss and/or the need for transfusion [6]. For example, the rapid determination of blood haemoglobin levels is essential, for the triage of patients in emergency departments [7], and tracking of changes in haemoglobin, to detect occult bleeding, has the potential to be lifesaving during critical care. Therefore, in the hospital setting, there is growing interest in rapid and continuous techniques for measuring haemoglobin and changes in haemoglobin.

Recently, noninvasive technologies have been developed that allow haemoglobin to be measured immediately without the need for intravenous access or having to take venous, arterial, or capillary blood. Moreover, with these technologies haemoglobin can be continuously measured in patients with active bleeding, to guide the start and stop of blood transfusions and to detect occult bleeding. Recent studies on the accuracy of the devices showed promising results in terms of accuracy of hemoglobin measurement compared to laboratory determination. The present review gives an overview on the technology itself and reviews the current literature on the subject.

1. Background

Trauma related haemorrhagic anaemia is rarely diagnosed by physical examination alone but typically includes measurement of blood haemoglobin, one of the most frequently ordered laboratory tests. Recently, noninvasive technologies have been developed that allow haemoglobin to be measured immediately without the need for intravenous access or having to take venous, arterial, or capillary blood. Moreover, with these technologies haemoglobin can be continuously measured in patients with active bleeding, to guide the start and stop of blood transfusions and to detect occult bleeding.

2. Pulse CO-Oximetry

Pulse CO-Oximetry (Masimo Corp, Irvine, CA, USA) is the only commercially available technology that allows for the continuous noninvasive measurement of haemoglobin, referred to as SpHb. This technology uses a multiple wavelength, spectrophotometric sensor that may be an adhesive single use type for continuous monitoring or a reusable finger clip sensor for spot check assessments. Pulse CO-Oximetry allows the noninvasive measurement of carboxyhaemoglobin, methaemoglobin, oxygen content, Pleth Variability Index, along with standard pulse oximetry parameters, oxygen saturation, pulse rate, and perfusion index [9]. SpHb
measurement with Pulse CO-Oximetry is available in a number of devices designed for the continuous monitoring at the hospital bedside (Radical-7, Rad-87) or for spot check applications with hand held devices (Rad-57, Pronto) (Figure 1).

Most of the studies published thus far on the performance of SpHb measurement with Pulse CO-Oximetry assess the accuracy of continuous monitoring in surgical patients. Berkow and colleagues [8] investigated the accuracy of SpHb compared to laboratory CO-Oximetry measurement of 130 arterial blood samples from 29 complex spine surgery patients and found an absolute bias and standard deviation of 0.8 ± 0.6 g/dL. Causey et al. [10] studied both surgical and intensive care patients and found a similar bias of 0.29 g/dL. In a study on 44 patients with acute haemorrhage during surgery, Lamhaut et al. compared SpHb and capillary haemoglobin measurement to laboratory determination [11]. The authors obtained a total of 85 measurements, which showed a bias of only −0.02 g/dL (SD 1.39) and a precision of 1.11 g/dL (SD 0.83). However, in comparison to laboratory haemoglobin determination, the percentage of outliers was significantly higher with noninvasive than with capillary measurement. Conversely, when Frasca et al. [12] examined the performance of SpHb in 62 ICU patients providing 471 samples, the bias was 0.0 ± 1.0 g/dL compared to the reference laboratory haematology analyser. However the bias and standard deviation of capillary measurement by HemoCue was 0.3 ± 1.3 g/dL when compared to the reference haematology analyser, significantly higher than SpHb. In general continuous SpHb monitoring accuracy has been found to be comparable to invasive point of care capillary measurement, with some studies showing it to be slightly higher [12] and some studies showing it to be slightly lower [11] when used in the operating room and intensive care unit.

There have also been a few studies published in Emergency Room patients. Sjostrand et al. investigated the accuracy of SpHb using repetitive controls of venous blood samples from 30 patients in a tertiary care emergency room [13]. A total of 242 comparative data pairs were obtained, resulting in a mean deviation of −0.47 g/dL (CI −0.39 to −0.09) for SpHb. After exclusion of 5 patients due to low signal quality, the deviation decreased to −0.24 g/dL (CI −0.39 to −0.09). Chung and colleagues [14] from Inje University Seoul Paik Hospital in Seoul, Korea, studied the accuracy of SpHb compared to laboratory measurements from 217 patients presenting to the emergency department. The correlation coefficient between laboratory haemoglobin and SpHb was 0.81 in all patients indication of good agreement between the two methods of measurement. In a prospective study on 300 emergency patients in France, Gayat et al. compared spot check SpHb to laboratory analysis of venous blood [15]. The absolute mean difference between SpHb and laboratory measurements was 0.56 g/L (confidence interval (CI) 0.41 to 0.69), with a correlation coefficient of 0.80 (CI 0.74 to 0.84). The accuracy of spot check SpHb was also investigated in the outpatient setting by Raikhel [16]. In a prospective observational study, the accuracy of SpHb measurements and capillary measurement of haemoglobin were compared to laboratory haematology analyser measurements from venous blood samples. A total of 156 patients were included in the study, but noninvasive measurement was not possible in 4 patients after two attempts. In the remaining 152 patients, the mean deviation of SpHb from laboratory determinations was −0.5 g/dL (standard deviation (SD) 1.0), with a limit of agreement of −2.5 to 1.5. Results were comparable to haemoglobin determination using capillary blood, with a mean deviation of 0.3 g/dL (SD 1.0) and a limit of agreement of −1.7 to 2.3.

Although the vast majority of published evaluations of SpHb with Pulse CO-Oximetry have been accuracy studies, the true clinical benefit of the technology may be as a trend monitor to detect unexpected changes in haemoglobin, such as with occult bleeding, or to confirm expected changes in haemoglobin as they occur during and after transfusion of red blood cells (Figure 2). Some studies have included an assessment of trend accuracy in the evaluation of SpHb. Berkow examined the magnitude and direction of changes in SpHb when laboratory haemoglobin changed by more than 1.5 g/dL between sequential measurements and concluded that SpHb trended with changes in laboratory haemoglobin but because the average changes were less than 3 g/dL more studies were needed [8]. Figure 3 shows continuous SpHb and intermittent laboratory values during one spinal surgery case in a 69-year-old female. Colquhoun et al. [17] used the four-quadrant plot and the polar plot method to assess trending of SpHb compared to laboratory measurements in 20 patients undergoing major lumbar and low thoracic spine surgery. The four-quadrant plot showed that 94% of SpHb readings outside of the central exclusion zone to eliminate clinically insignificant changes corresponded with the correct directionality. Similarly, the polar plot indicated that 90% of changes in SpHb were within the limits of acceptable trending. Frasca et al. [12] used regression plots of differences in consecutive haemoglobin values reported by
Table 1: Differences in red blood cell transfusions when clinicians used standard of care blood management or added SpHb monitoring to guide transfusions in (a) 327 surgery patients with expected low blood loss and (b) 106 surgery patients with expected high blood loss.

<table>
<thead>
<tr>
<th>(a) Low blood loss surgery (n = 327)</th>
<th>Standard care group (n = 157)</th>
<th>SpHb Group (n = 170)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients receiving a transfusion N (%)</td>
<td>7 (4.5%)</td>
<td>1 (0.6%)</td>
<td>0.03</td>
</tr>
<tr>
<td>Total units transfused, N (mean)</td>
<td>15 (0.10)</td>
<td>1 (0.1)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b) High blood loss surgery (n = 106)</th>
<th>Standard care group (n = 61)</th>
<th>SpHb Group (n = 45)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBC transfusions per subject, mean ± SD units</td>
<td>1.9 ± 2.3</td>
<td>1.0 ± 1.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RBC transfusions per subject receiving a transfusion, mean ± SD units</td>
<td>3.9 ± 1.7</td>
<td>2.3 ± 1.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Transfused patients receiving &gt;3 RBC, % units</td>
<td>73</td>
<td>32</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Time to transfusion start after need established, mean ± SD min</td>
<td>50.2 ± 7.9</td>
<td>9.2 ± 1.7</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

SpHb, capillary haemoglobin measurement with HemoCue, and satellite CO-Oximetry measurements compared to central laboratory measurements. SpHb demonstrated the best trending of the three methods with a concordance coefficient of 0.79. Concordance coefficients for satellite CO-Oximetry and HemoCue were 0.74 and 0.76, respectively.

Indeed, it is the continuous data and trending ability that differentiates this technology from intermittent laboratory or point of care measurements. In fact, the purpose of continuous monitoring is not to replace intermittent laboratory measurements but to improve clinical care by augmenting the data available to the clinician for assessment of the patient. Two preliminary investigations on how SpHb can help guide transfusion decisions, published thus far only as abstracts, support this notion.

The first study, a randomized controlled trial in 327 surgery patients with expected low blood, found that when SpHb monitoring was added to standard care, the frequency of blood transfusions dropped from 4.5% to 0.6% (87% decrease) and the mean units transfused dropped from 0.1 to 0.01 units per patient (90% decrease) (Table 1(a)) [18]. The second prospective cohort study conducted in 106 patients at risk for high blood loss showed that the addition of SpHb monitoring to standard care resulted in a reduction from 1.9 ± 2.3 units to 1.0 ± 1.5 units (47% decrease) in the average number of RBC units transfused and a reduction from 73% to 32% (56% decrease) in the frequency of multiunit RBC transfusions (Table 1(b)) [19]. With SpHb monitoring clinicians were able to initiate transfusions about 9 minutes faster compared to physicians not using the technology, because they did not have to wait for a laboratory haemoglobin value.

3. Discussion

The rapid and noninvasive measurement of haemoglobin and the availability of continuous haemoglobin data have the potential to be enormously useful in clinical practice in a variety of situations, such as in trauma, gastrointestinal bleeding, in the perioperative setting, or for guiding blood management during invasive interventions [20, 21].

The results from evaluations of SpHb with Pulse CO-Oximetry are promising. In many settings SpHb measurements appear to have similar accuracy as capillary haemoglobin determination when compared to laboratory analysis. Nevertheless, there is room for improvement of the technology (which is on-going), for educating clinician on the best use of the technology and adapting clinical pathways to take advantage of this new tool [16]. In the author’s eyes, because the technology is not intended to replace laboratory measurements, it is less important to receive a measurement that exactly mirrors a laboratory value, rather than to provide continuous information regarding the changes or stability of haemoglobin. For the spot check applications, the immediacy of data and noninvasive nature of the device make it ideal for
prehospital triage decisions such as choosing the right hospital. At the hospital, this technology has the potential to assist emergency department staff in making triage priorities and in assigning staff and infrastructure. The ease of use of these devices allows for the universal screening of all presenting patients for anaemia which could indicate occult bleeding or other disease processes requiring intervention.

More data from prospective studies is needed to confirm the reliability of this method to guide therapy during surgery or on-going bleeding. Additionally, prospective randomised trials would be desirable to investigate the potential of SpHb monitoring to reduce blood transfusions during surgery or in the intensive care unit.

In conclusion, SpHb by Pulse CO-Oximeter is a promising new medical technology that has the potential to improve the process of care and patient outcomes in many different healthcare settings.

**Conflict of Interests**

The authors declare that they have no conflict of interests.

**References**


Research Article

Feasibility of Remote Real-Time Guidance of a Cardiac Examination Performed by Novices Using a Pocket-Sized Ultrasound Device

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Background. The potential of pocket-sized ultrasound devices (PUDs) to improve global healthcare delivery is limited by the lack of a suitable imaging protocol and trained users. Therefore, we investigated the feasibility of performing a brief, evidence-based cardiac limited ultrasound exam (CLUE) through wireless guidance of novice users.

Methods. Three trainees applied PUDs on 27 subjects while directed by an off-site cardiologist to obtain a CLUE to screen for LV systolic dysfunction (LVSD), LA enlargement (LAE), ultrasound lung comets (ULC+), and elevated CVP (eCVP). Real-time remote audiovisual guidance and interpretation by the cardiologist were performed using the iPhone 4/iPod (FaceTime, Apple, Inc.) attached to the PUD and transmitted data wirelessly. Accuracy and technical quality of transmitted images were compared to on-site, gold-standard echo thresholds.

Results. Novice versus sonographer imaging yielded technically adequate views in 122/135 (90%) versus 130/135 (96%) ($P < 0.05$). CLUE’s combined SN, SP, and ACC were 0.67, 0.96, and 0.90. Technical adequacy (%) and accuracy for each abnormality ($n$) were LVSD (85%, 0.93, $n = 5$), LAE (89%, 0.74, $n = 16$), ULC+ (100%, 0.94, $n = 5$), and eCVP (78%, 0.91, $n = 1$).

Conclusion. A novice can perform the CLUE using PUD when wirelessly guided by an expert. This method could facilitate PUD use for off-site bedside medical decision making and triaging of patients.

1. Background

Although pocket-sized ultrasound devices (PUDs) can augment the physical exam, their potential to improve global healthcare delivery in the emergent setting or in areas of limited resources has been limited by the lack of a suitable imaging protocol and trained users [1]. We have previously shown that an evidence-based, 5-minute “quick-look” cardiac limited ultrasound exam (CLUE) has diagnostic and prognostic value [2], affects medical decision making [3], and can be taught to internal medicine residents [4]. Unlike the traditional bedside cardiac examination, CLUE has the potential for wireless transmission. Recent reports have shown the feasibility of remotely mentored ultrasound examination to evaluate apnea and pneumothorax in trauma [5] and in off-line remote expert echo interpretation using a smartphone-based application [6]. We investigated the feasibility of utilizing low-cost, readily available wireless video conferencing software to guide novice users in performing CLUE in real time.

2. Methods

The CLUE examined 4 targets using 4 previously-validated, nonquantitative ultrasound “signs” [2]. In brief, the parasternal long axis view was assessed for LV systolic dysfunction (LVSD) and left atrial enlargement (LAE). LVSD was present if the anterior leaflet of the mitral valve during diastole did not appear to encroach upon the LV outflow tract and approach the septum to within approximately 1 cm by nonquantitative estimation. LAE was present if the anteroposterior diameter of the LA appeared larger than that of the overlying aorta throughout the cardiac cycle. Longitudinal views at the mid-infraclavicular intercostal space of each lung apex were assessed for extravascular lung water by ultrasound lung...
Table 1: Components of the CLUE Protocol.

<table>
<thead>
<tr>
<th>Signs</th>
<th>Probe site</th>
<th>Diagnostic targets</th>
<th>Normal</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVSD</td>
<td>Parasternal long axis</td>
<td>Distance from the anterior leaflet of the mitral valve to the septum during diastole</td>
<td>≤1 cm</td>
<td>&gt;1 cm</td>
</tr>
<tr>
<td>LAE</td>
<td>Parasternal long axis</td>
<td>Anteroposterior diameter of the LA versus overlying aorta throughout the cardiac cycle</td>
<td>Aorta &gt; LA</td>
<td>LA &gt; Aorta</td>
</tr>
<tr>
<td>ULC+</td>
<td>Bilateral lung apices</td>
<td>Number of lung comets in either lung apex</td>
<td>&lt;3</td>
<td>≥3</td>
</tr>
<tr>
<td>eCVP</td>
<td>Subcostal</td>
<td>Percent luminal diameter reduction of IVC with respiration, without forced &quot;sniffing&quot;</td>
<td>&gt;50%</td>
<td>≤50%</td>
</tr>
</tbody>
</table>

Figure 1

comet-tail artifacts (ULC+) [7], considered present when 3 vertical hyperechoic lines per image were seen to emanate from the pleural line in the near field and reach the far field, in either lung apical view. Each lung apex was a separate CLUE view and a positive ULC sign was defined when either lung apex or both lung apices were ULC+. The subcostal longitudinal view of the proximal intrahepatic inferior vena cava as it entered the right atrium, within approximately 1-2 cm of the diaphragm, was assessed for elevated central venous pressures (eCVP), defined when the IVC appeared plethoric by visual interpretation with parallel vessel walls and a luminal diameter reduction of <50% with respiratory motion of the diaphragm, without forced “sniffing” (see Table 1).

Three trainees (medical student, intern, and pharmacy resident) with less than 1-hour device orientation and no prior ultrasound experience or training performed the CLUE using a PUD (either the Vscan, GE Healthcare, or the P10, Siemens Healthcare) on 27 subjects (22 outpatients and 5 normal volunteers) at a medical office while being directed by an off-site cardiologist through an iPhone 4 or iPod (Apple Inc.) attached to the PUD as follows. The iPhone or iPod had been affixed to the base of the PUD using a small commercially available dashboard phone mount so that the iPhone/iPod’s front facing 0.3 megapixel VGA camera was directed at the opposing PUD display screen (see Figures 1, 2, and 3). Using the application Apple FaceTime (WPA2 Enterprise, 128-bit AES Encryption; HIPAA Compatible; VGA resolution; 30 fps), data was transmitted wirelessly through currently available off-the-shelf Wi-Fi networks (2.4 GHz, 802.11g, wireless router) to the cardiologist’s receiving iPod. The cardiologist provided remote audiovisual guidance with real time feedback on operation of the PUD, image acquisition, and interpretation for CLUE signs to the trainee. The Vscan employs a 1.7–3.8 MHz phased array probe and the Siemens P10 uses a 2–4 MHz phased array probe. Only one device was used throughout a CLUE exam. As the study tested real-time wireless guidance, no images were stored or reviewed off-line. All subjects were asymptomatic. Trainees, the sonographer, and echocardiography expert were blinded to their clinical histories.

Screening accuracy and technical quality of transmitted CLUE images were compared to gold-standard echocardiograms that included lung apical imaging performed on a standard platform (Acuson Cypress, Siemens Healthcare). The gold-standard echocardiograms were obtained by a registered sonographer blinded to the CLUE results according to standard guidelines [8] and was interpreted by an expert.
LVSD was defined as an interpreted ejection fraction <40% using the interpreter’s discretion of all available methods including nonquantitative expert estimation, the biplane method of discs (modified Simpson’s rule), or fractional shortening. LAE was defined by an anteroposterior LA diameter >4.0 cm or LA volume index >28 mL/m² measured using the area-length method [8]. Interpretation of the eCVP and ULC+ findings on the echocardiogram used the same method as the PUD. All images were assigned a quality score: 0 (no image), 1 (only motion detected; off-axis), 2 ("suboptimal," poor delineation of structures), 3 ("adequate" for diagnosis of particular sign), or 4 ("optimal," good delineation of all structures equivalent to idealized standard echocardiographic view). Views with scores >2 were considered technically adequate.

The diagnostic sensitivity, specificity, positive and negative predictive values, and accuracy were derived for the CLUE diagnostic criteria for LVSD, LAE, ULC+, and eCVP by comparing the interpretation of technically adequate CLUE views with the results of LVSD, LAE, ULC+, and eCVP from the reference standard echocardiogram. The Scripps Institutional Review Board approved the study.

3. Results

Successful transmission and guidance occurred in 27/27 patients among the three trainees: trainee 1: 10 patients; trainee 2: 8 patients; trainee 3: 9 patients. All of the 27 expert-guided CLUEs were successfully completed in less than 5 minutes. Two transmissions (7%) were dropped and reinitiated. Guided novice versus sonographer imaging yielded technically adequate CLUE views in 122/135 (90%) versus 130/135 (96%), respectively (\(P = 0.05\)). CLUE had a combined sensitivity, specificity, and accuracy of 0.67, 0.96, and 0.90 for echo thresholds. Technical adequacy (%) and accuracy for each abnormality were LVSD (85%, 0.93, \(n = 5\)), LAE (89%, 0.74, \(n = 16\)), ULC+ (100%, 0.94, \(n = 5\)), and eCVP (78%, 0.91, \(n = 1\)) (see Table 2).

4. Discussion

This feasibility study demonstrated that novices could perform a specific 4-view CLUE appropriate for PUDs, when guided in real time by an expert using wireless transmission. In spite of lesser technical quality than standard echocardiographic views, transmitted images provided substantial accuracy as a bedside examination. In the ASE REWARD study [1], volunteer physicians and sonographers screened 1030 subjects in India with PUD, then uploaded the images to a “cloud” where they were accessed and reviewed by expert physicians in other countries. However, this study required expert sonographers and had a median time interval of 12 hours and 11 minutes prior to image interpretations, which is inadequate for emergency application. Instead, our novel diagnostic and teaching method combines a simplified cardiac imaging protocol with inexpensive technologies and could facilitate the use of ultrasound for immediate off-site bedside medical decision making and triaging of out-of-hospital patients with common presentations of chest pain, unexplained dyspnea, or hypotension. For instance, in the field or the ambulance ride to the hospital, emergency medical personnel could perform this diagnostic technique with remote guidance by experts such as emergency physicians or cardiologists trained in the CLUE. LVSD has been shown to occur in many acute disease states including acute coronary syndromes, septic shock, and acute heart failure [9]. LAE has also been shown to be a marker for the presence of significant cardiac findings on echocardiography [10]. ULC+ can occur in patients with acute pulmonary edema or interstitial disease [11]. Lastly, evaluating the inferior vena cava for eCVP can be used in the assessment of different types of shock (septic, cardiogenic, and hypovolemic) as well as in cardiac tamponade and pulmonary embolism. Earlier diagnosis of these time-sensitive and critical conditions may
lead to better patient outcomes through earlier management decisions.

Limitations of these observations are as follows. The body mass indexes of the patients, which can affect image acquisition, were not measured. However, patients were typical of those seen in outpatient cardiology practice and none of the 27 patients were "morbidly obese" by subjective estimates. There was inadequate power to determine intertrainee differences due to the small number of pathologies and patients. By focusing on the average technical adequacy score over the training period, our observations likely underestimated the trainee’s ability by the end of the study. Although this study showed that real time remote guidance of a cardiac examination performed by novices using a PUD is feasible in the outpatient setting and its brevity (<5 minutes) is clinically practical for emergency situations, further and larger studies incorporating additional signs such as pericardial effusion or right ventricular dilation are needed to apply this diagnostic and teaching method in the out-of-hospital emergency setting.

Disclaimer

The opinions, results, and conclusions reported in this paper are those of the authors and are independent of any funding sources.

Authors’ Contribution

Mai, Ahn, Phillips, Agan, and Kimura had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design were made by Mai, Ahn, Phillips, and Kimura. Acquisition of data were done by Ahn, Phillips, and Kimura. Analysis and interpretation of data were carried by Mai, Ahn, Phillips, Agan, and Kimura. Drafting of the paper was made by Mai, Ahn, Phillips, and Kimura. Statistical analysis was performed by Mai, Ahn, Phillips, Agan, and Kimura. Administrative, technical, and material support was provided by Kimura. Study supervision was performed by Kimura.

Acknowledgments

Robert J. Eastin, Pharm. D., and Casey L. Wahlstrom, RDCS, contributed to the acquisition of data. David Shaw, MD, and the graduate medical education office of Scripps Mercy Hospital have provided the Vscan (GE) PUD.

References


Table 2: Comparison of technically adequate CLUE views and diagnostic accuracy for each abnormality between guided-novice PUD and gold-standard echocardiogram.

<table>
<thead>
<tr>
<th>Signs</th>
<th>Novice quality (±SD, n)</th>
<th>Echo quality (±SD, n)</th>
<th>Sens. (%)</th>
<th>Spec. (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>ACC. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVSD</td>
<td>3.1 ± 0.8 (85)</td>
<td>3.7 ± 0.6 (96)</td>
<td>80</td>
<td>95</td>
<td>80</td>
<td>95</td>
<td>93</td>
</tr>
<tr>
<td>LAE</td>
<td>3.1 ± 0.7 (89)</td>
<td>3.7 ± 0.6 (95)</td>
<td>69</td>
<td>82</td>
<td>85</td>
<td>64</td>
<td>74</td>
</tr>
<tr>
<td>ULC+</td>
<td>3.2 ± 0.4 (100)</td>
<td>3.9 ± 0.4 (100)</td>
<td>40</td>
<td>100</td>
<td>100</td>
<td>94</td>
<td>94</td>
</tr>
<tr>
<td>eCVP</td>
<td>3.1 ± 1.0 (78)</td>
<td>3.4 ± 0.7 (89)</td>
<td>100</td>
<td>96</td>
<td>96</td>
<td>100</td>
<td>96</td>
</tr>
<tr>
<td>Total</td>
<td>3.2 ± 0.7 (90)</td>
<td>3.7 ± 0.5 (96)</td>
<td>67</td>
<td>96</td>
<td>92</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

n: number of abnormality; quality scores reported as mean ± SD; Sens.: sensitivity; Spec.: specificity, PPV: positive predictive value; NPV: negative predictive value; ACC.: accuracy.


Review Article
Pitfalls in Emergency Department Focused Bedside Sonography of First Trimester Pregnancy

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Background. Bedside sonography performed by emergency physicians is frequently utilized for real-time clinical decision-making in the emergency department (ED) setting. This includes the sonographic evaluation of pain or bleeding in the first trimester of pregnancy. The detection of intrauterine pregnancy (IUP) or life-threatening conditions, including ectopic pregnancy, is critical.

Objectives. This paper will review several important pearls and avoidable pitfalls of this diagnostic modality by brief presentation of illustrative cases followed by discussion of key principles.

Case Reports. Three patients evaluated in the ED for bleeding or pain occurring during the first trimester of pregnancy will be presented.

Conclusions. When conducting emergency bedside ultrasound for the evaluation of first trimester pregnancy, it is important to avoid common pitfalls that can place your patient at risk.

1. Introduction

In recent years, studies have demonstrated that emergency physicians (EPs) can competently perform focused bedside sonography for the evaluation of first trimester pregnancy in the emergency department (ED) [1, 2]. Indeed, EP utilization of ultrasound in first trimester pregnancy is becoming increasingly more common and accepted within emergency care. The American College of Emergency Physicians (ACEP) lists emergency ultrasound in pregnancy as a core area of ultrasound proficiency for the emergency medicine (EM) specialist. In addition, all EM residents are now required to become facile with bedside ultrasound [3]. The detection of potentially life-threatening problems in early pregnancy, particularly ectopic pregnancy, is a fundamental skill [4, 5]. Given the widespread use of this modality, we seek to point out several important and avoidable pitfalls in bedside sonography for first trimester pregnancy through use of representative cases. Important pearls and strategies to avoid these pitfalls are highlighted.

2. Case Presentations

2.1. Case 1: βhCG Level below the Discriminatory Zone. A 27-year-old female, Gravida 2, Para 1, presented to the ED following delivery by cesarean section four months prior, with absence of menstruation since the time of delivery. She presented with severe sharp cramping lower abdominal pain of 18-hour duration. Her vital signs were as follows: temperature 37 degrees centigrade, blood pressure 133/84 millimeters of mercury, heart rate of 156 beats per minute, and a normal respiratory rate and room air oxygen saturation. A urine pregnancy test was positive. The serum quantitative beta human chorionic gonadotropin (βhCG) level was 726 international units per liter (IU/L). Focused, screening bedside transabdominal ultrasound followed by transvaginal ultrasound examination to evaluate for IUP performed by the treating EP revealed free fluid in the abdomen and the absence of a gestational sac in the uterus (Figure 1). Based on the finding of a positive βhCG test and free intraperitoneal fluid on sonogram, the gynecology service was emergently consulted. Despite a quantitative βhCG level below the “discriminatory zone,” the patient underwent emergent laparoscopic right salpingectomy for ectopic pregnancy with evacuation of 500 mL of clotted blood from the peritoneum.

2.2. Case 2: βhCG Level near or above the Discriminatory Zone and an Empty Uterus. A 26-year-old female, Gravida 4,
Para 2, presented to the ED with suprapubic cramping and dysuria. Her last menses was one month prior. Her vital signs were all normal. A urine pregnancy test was positive. Urine dipstick revealed moderate blood and small leukocyte esterase. An EP performed focused, bedside emergency transabdominal followed by transvaginal ultrasound examination which was nondiagnostic; no IUP was identified. The quantitative βhCG level was 1,484 IU/L. Given the βhCG level just below the “discriminatory zone” and a concomitant diagnosis of possible urinary tract infection (UTI), the patient was treated with antimicrobials for UTI in pregnancy and discharged home. Given the non-diagnostic ultrasound, the patient was instructed to return to the ED or her gynecologist in 2-3 days for a repeat βhCG level determination and a repeat ultrasound examination.

Following patient discharge, free intraperitoneal fluid in the cul de sac was identified on routine ED ultrasound quality improvement review (Figures 2 and 3). This fluid was not fully appreciated by the treating provider at the time of the initial study. The patient did not follow up as instructed but eight days later returned to the ED complaining of right lower quadrant abdominal pain. Her vital signs were again normal. During the return visit, the serum βhCG level had risen to 5,775 IU/L. Emergency bedside transabdominal and transvaginal ultrasound revealed no IUP. The gynecology service was consulted, and further diagnostic transvaginal ultrasound imaging by the gynecology service revealed a 5.5 cm right-sided mass suspicious for an ectopic pregnancy. The patient underwent a laparoscopic right salpingectomy with a postoperative course complicated by pelvic hematoma.

2.3. Case 3: The EP Sonographer’s Unique Vantage Point in Synthesizing Clinical, Laboratory, and Imaging Data. A 23-year-old female, Gravida 3, Para 2, presented complaining of cramping pelvic pain and vaginal bleeding. Her last menses was one month prior. A urine pregnancy test was positive. The quantitative βhCG level was 398 IU/L. Focused, bedside transabdominal and transvaginal ultrasound performed by the EP was suspicious for ectopic pregnancy based on the lack of a recognized IUP and focal pain and tenderness in the right lower quadrant. Per local protocol, a repeat ultrasound examination was immediately performed in the radiology suite. The radiologist determined that there was an abnormal fluid collection around the right ovary most consistent with a hematoma (Figure 4). The study was formally interpreted as no definite adnexal mass and no definite IUP. The patient was further evaluated by the gynecology service due to the EP’s continued suspicion for ectopic pregnancy. She was ultimately discharged home following specialty consultation with instructions to return in 2 days for repeat serum βhCG level and follow-up ultrasound examination.

The patient returned to the ED within 48 hours, complaining of worsening pain, vaginal bleeding, and lightheadedness. Vital signs revealed a heart rate of 121 beats per minute and a blood pressure of 146/74 millimeters of mercury. The βhCG level had risen to 455 IU/L, and transvaginal ultrasound (bedside and in the radiology suite) performed during the repeat visit confirmed a right-sided ectopic pregnancy with associated free intraperitoneal fluid (Figure 5). The patient initially underwent a laparoscopic right salpingectomy, which required intraoperative conversion to open laparotomy because of the presence of adhesions between the uterus and anterior abdominal wall, as well as a significant number of blood clots obscuring the view of the camera. The patient ultimately had an uneventful recovery.

3. Discussion

3.1. Pitfall I: Failure to Obtain a Diagnostic Ultrasound Imaging Study When the βhCG Quantitative Value Is below the Discriminatory Zone. The first case illustrates a common misperception with first trimester emergency ultrasound. That is, an ectopic pregnancy is unlikely to be diagnosed by bedside ultrasound when the βhCG is below the “discriminatory zone.” Published guidelines regarding the “discriminatory zone” often lead to confusion in the approach to patients with early pregnancy. The discriminatory zone is defined as the level of βhCG above which an IUP can be reliably detected by ultrasound [6]. This level is frequently defined as 1,500 IU/L by transvaginal ultrasound and 6,500 IU/L by transabdominal ultrasound [7–9]. Though the discriminatory zone concept was developed when only transabdominal ultrasound was standard, it is now routine to obtain a transvaginal pelvic ultrasound to evaluate IUP in early...
pregnancy. The discriminatory zone range for transvaginal ultrasound varies among practitioners and institutions but typically falls between 1,500 IU/L and 3,000 IU/L [10]. A more conservative approach is to use the lower end of this range (1,500 IU/L) in emergency clinical decision-making. Ectopic pregnancy, however, may be detected at βhCG levels well below the lower end of the discriminatory zone range [11].

In comparing 6 different strategies for diagnosing IUP, the strategy of ultrasound for all, as opposed to ultrasound for only those with a quantitative βhCG above the discriminatory zone, was the most sensitive [12]. Indeed, a study conducted by Condous and his colleagues showed that use of the 1,500 IU/L level as a cutoff is only 15% sensitive in detecting ectopic pregnancy [13]. Further, a recent ED-based study again revealed the lack of ability of βhCG level to assist in determining intrauterine versus ectopic pregnancy [14]. Therefore, it is important for the EP to consider the diagnosis of ectopic pregnancy with pain or bleeding and consider diagnostic ultrasound even if the βhCG level falls below the discriminatory zone threshold value.

3.2. Pitfall 2: Failure to Obtain Additional Diagnostic Imaging or Specialty Consultation When Faced with a βhCG Quantitative Level near or above the Discriminatory Zone in the Setting of an Empty Uterus. The second case illustrates another common pitfall. The American College of Emergency Physicians (ACEP) guidelines state that the primary goal of obstetric ultrasound in the ED is to determine if an IUP is present [3]. Further diagnosis by bedside ultrasound when an IUP cannot be identified has lower sensitivity rates. Since the EP recognized that there was no IUP present in the setting of a βHCG level near the discriminatory zone, further radiologic ultrasound on the initial visit would have been appropriate.

In addition, a study of women at risk for ectopic pregnancy confirms that the presence of echogenic fluid is a significant risk factor for the ultimate diagnosis of ectopic pregnancy [15]. Whether or not the treating EP appreciated the small amount of free fluid detected during the quality improvement image review, the lack of an IUP despite a βHCG near or above the discriminatory zone should have prompted consideration of further diagnostic imaging. The bottom line is that it is prudent for the EP to consider this scenario (βhCG near or above the discriminatory zone accompanied by lack of a defined IUP on ultrasound examination of the uterus) to be high risk for ectopic pregnancy until proven otherwise, prompting further diagnostic imaging or specialty consultant engagement to aid in decision-making.

3.3. Pitfall 3: Failure to Trust One’s Judgment as the Treating Clinician When Synthesizing Historical, Examination, and Diagnostic Imaging and Laboratory Data. The final case illustrates the potential pitfall of not trusting your instincts as the clinician sonographer present at the bedside. The ability of EPs to make decisions based on bedside ultrasound of first trimester pregnancy has been illustrated in numerous studies [5, 15, 16]. One such study revealed a 96% concordance rate with radiologic interpretation [17]. In addition, the EP has the added benefit of being at the patients’ bedside. This provides the unique vantage point of synthesizing historical, examination, laboratory, and imaging findings in the overall clinical context. When the picture just does not seem to fit, consider further diagnostic imaging or specialty consultation. In the case presented, these additional steps were taken, and the diagnosis was ultimately made at the time of follow-up. This underscores the importance of detailing and documenting strict follow-up precautions, including indications to return to the ED and the need for frequent serial reevaluations.

4. Conclusion

When conducting emergency bedside ultrasound for the evaluation of first trimester pregnancy, it is important to avoid
common pitfalls that can place your patient at risk. Primarily, all patients with a positive pregnancy test should undergo ultrasound evaluation regardless of the $\beta$HCG level. Second, if a definitive IUP is not visualized when the $\beta$hCG level is near or above the discriminatory zone, maintain a very low threshold for further diagnostic imaging and, in some cases, specialty consultation. Finally, trust your judgment. EPs have a unique vantage point in being able to synthesize historical, examination, laboratory, and imaging data, as well as consideration of alternate diagnoses. If in doubt, review your findings with your consultants to come up with the most likely diagnosis and ensure timely follow-up evaluation for your patient.

References


Research Article

Image and Imaging an Emergency Department: Expense and Benefit of Different Quality Assessment Methods

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Introduction. In this era of high-tech medicine, it is becoming increasingly important to assess patient satisfaction. There are several methods to do so, but these differ greatly in terms of cost, time, and labour and external validity. The aim of this study is to describe and compare the structure and implementation of different methods to assess the satisfaction of patients in an emergency department.

Methods. The structure and implementation of the different methods to assess patient satisfaction were evaluated on the basis of a 90-minute standardised interview.

Results. We identified a total of six different methods in six different hospitals. The average number of patients assessed was 5012, with a range from 230 (M5) to 20 000 patients (M2). In four methods (M1, M3, M5, and M6), the questionnaire was composed by a specialised external institute. In two methods, the questionnaire was created by the hospital itself (M2, M4). The median response rate was 58.4% (range 9–97.8%). With a reminder, the response rate increased by 60% (M3).

Conclusion. The ideal method to assess patient satisfaction in the emergency department setting is to use a patient-based, in-emergency department-based assessment of patient satisfaction, planned and guided by expert personnel.

1. Introduction

In recent decades, there have been major technical improvements in the health systems of western countries [1]. In this era of high technology, patient satisfaction has become increasingly important [1, 2]. Since the 1950s, patient satisfaction has had an important role in the evaluation of medical care [2].

There are various reasons why it may be profitable for a hospital to perform surveys on patient satisfaction [3]. Several studies have found that satisfied patients suffer less pain [4, 5]; they require fewer (secondary) operations and more rarely have complications [4, 5]. Moreover, satisfied patients exhibit better compliance [4–6]. This simplifies therapy and enhances treatment efficiency [6]. There are also reports that satisfied patients stay for up to 50% less time in hospitals [1, 4, 7]. On the other hand, patient dissatisfaction is a decisive reason for complaints after leaving the hospital [8] as well as for litigation [5, 9]. Thus, an improvement in patient satisfaction can make a major contribution to cost reduction and to maintaining competitiveness [3]. Performing surveys on patient satisfaction is, therefore, an essential patient-centred improvement process [10].

A very wide variety of methods are now in use to assess patient satisfaction with some drastic differences in costs, time expenditure, and external validity [1]. Although there have been extensive discussions on patient satisfaction in itself, no comparison has yet been performed between the various conventional methods. In particular, there has been no cost benefit analysis. The objective of the present study is to compare the structure and implementation of different patient satisfaction surveys in emergency wards.
2. Methods

2.1. Questionnaire and Interview. On the basis of empirical considerations and after studying the relevant literature, the questionnaire was created by a quality manager, an interview expert, and a clinician with epidemiological training. The standardised interview was performed by a single independent person, who had previously been trained in performing interviews. In each case, the person interviewed was responsible for patient satisfaction in the corresponding emergency ward. The interview lasted 90 minutes.

2.2. Contents of the Questionnaire. The questionnaire covered the method of assessing the patient (mode of assessment, site of assessment, and time point of assessment), the financial expenditure (preparation of the project, commissioning an institute, expenditure per patient, and expenditure for evaluating the data), and the reliability of the data obtained (response and response after reminder). See Table 1.

2.3. Selection of Emergency Wards. The emergency wards were randomly selected and contacted in writing. A total of six different assessment methods were recorded. A typical reference hospital was selected for each assessment method. Telephonic assessment was excluded from the study.

2.4. Definition of the Costs. All expenses that arise from the organisation and the implementation of the assessment of patient satisfaction were recorded. The costs were given per measurement cycle, as this includes one-off basic costs that are independent of the duration. The costs that arise directly for the individual patient—such as distribution and digitalization—are given per patient, as the number of patients varies greatly between the methods. The costs that could not be given directly during the interviews were estimated together with the interview partner and then validated by a quality expert. Table 2 shows the different phases of the performance of a patient assessment.

2.5. Time Expended. All staff deployment that arose in direct connection with the assessment of patient satisfaction was rated as work performed. If persons outside the hospital were deployed, this was counted as costs. In order to make it possible to assess the costs independently of the country and the currency, the work unit (WU) was introduced, where 100 WUs correspond to one hour of work. For the conversion into Swiss Francs, a mean gross hourly wage of CHF 58.- (≈ 46.40 Euro) was assumed.

3. Results

A total of six different methods of assessing patient satisfaction were investigated (Figure 1). On average, 5012 patients per month were interviewed, ranging from 230 patients per month with M5 to 20000 patients per month with M2. All of the questionnaires were similar in length. For four of the methods, an external institute was commissioned to create a questionnaire (M1, M3, M5, and M6); for the other two methods (M2, M4), the questionnaire was created by the corresponding hospital. The hospitals in M1 and M3 commissioned an institute, and also independently created their own questions. For two of the methods, the questionnaire was provided online (M1, M5), but for the other four methods it was printed on paper (M2–M4, M6). For three methods, the assessment was performed at home (M1, M3, and M4) and for the other three on discharge from the hospital. A reminder was only sent for M3. The mean response rate was 58.4% (range 9–97.8%). The reminder (M3) increased the response
rate by 60%. For the methods in which the assessment was performed in the hospital, the mean response rate was 69.8%, which is much higher than when the questionnaires were provided at home (46.8%). When the questionnaire was issued at the emergency ward to be completed at home (M2), the response rate was 35%. Invalid questionnaires were more frequent with printed questionnaires than online. In four methods, the recorded data were evaluated externally (M1, M3, M5, and M6), whereas for two methods the evaluation was performed by the corresponding emergency ward (M2, M4). The results from three methods were immediately available (M1, M5, and M6) and those from the other three methods after three months (M2–4). Benchmarking was possible for four methods (M1, M3, M5, and M6), this was always performed by external institutes.

There were differences between the individual methods with respect to both the costs and the time expended, see Table 3. The cheapest method was M5, for which the creation of the questionnaire, the preparation of the infrastructure, and the evaluation of the data were all performed by an external institute. The most expensive was method M2, for which the emergency ward performed the whole patient assessment alone. Commissioning an external institute was markedly less expensive than creating and evaluating the questionnaire internally. The most expensive factor was the creation of the questionnaire. Its creation within the hospital (M2, M4) and its modification (M1, M3) required much more time.

4. Discussion

The present study uses an interview for the description of the advantages and disadvantages of six different methods to assess patient satisfaction. There are marked differences between the individual methods with respect to costs, time expended, and the response rate.

(i) Findings on the response rate are the following.

(a) The response rate is markedly higher if patient satisfaction is assessed in the hospital.
(b) Only a few patients will comply with a letter that requests them to complete the questionnaire on discharge from the hospital. Thus, this mode of assessment cannot be recommended.
Table 3: Financial expenditure and time expended.

<table>
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<tr>
<th></th>
<th>M1</th>
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<th>M4</th>
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<td>2800</td>
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<tr>
<td>Infrastructure</td>
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<td>9600.-*</td>
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<td>2500.-*</td>
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<td>600.-</td>
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*Values estimated.
**Costs included if institute commissioned.

(c) A very good response rate can be recorded by online recording within the hospital, even though this involves additional technical and staff deployment. For example, older patients may require specific support when completing the questionnaire on the computer.

(d) If a member of the hospital staff personally inquires about the patient assessment, this raises the response rate. Nevertheless, it must be born in mind that persons participating directly in the treatment may not be involved in the patient assessment, in order to avoid prejudicing the patient's response.

(e) It is known from the literature [2], the rate of response is markedly increased by a reminder.

(ii) Costs and resources are the following.

(a) Assessments developed and performed by the hospitals themselves require relatively high investment and personnel resources.

(b) If an existing questionnaire is modified within the hospital, this requires much more additional time and, therefore, additional costs. Moreover, the hospital staff often lack the expertise needed to implement high-quality data collection and to estimate the resulting costs correctly in advance.

(c) It seems to be a cheaper alternative to commission an external assessment institute. This is particularly the case when the price includes not only the questionnaire and its evaluation, but also the infrastructure. Another advantage is that an assessment institute works with a cost budget, which can be clearly assessed by the corresponding hospital.

(iii) Additional points are the following points.

(a) Questionnaires from external assessment institutes are mostly validated.

(b) External institutes can provide reference values.

5. Weaknesses and Strengths of the Study

The present study has the following weaknesses.

(i) The resources needed to process the patient assessment forms were not always clearly defined by the hospitals and sometimes had to be estimated. This made it difficult to list the costs and could possibly have led to their underestimation.

(ii) In many hospitals, the resources linked to the planning of the patient assessment are not precisely documented. It is, therefore, possible that the time expended and the resulting costs were considerably underestimated.

(iii) Very different numbers of patients were assessed by each method.

In spite of these weaknesses, our data permit relatively clear conclusions. It would be worthwhile to support these by recording prospective data on the effective costs of patient assessments.

6. Conclusion

This study is the first comparison of different methods of performing assessments of patient satisfaction on emergency wards on the basis of examples. It was shown that patient-optimised online assessment performed in the hospital can give a very good response rate. The costs and the time expended can be greatly reduced if an external institute is
commissioned. This also offers the possibility of benchmarking. Nevertheless, further prospective studies are needed to validate our results and to deepen our knowledge.

References


