



## Advancements at the bedside: diagnostic and therapeutic tools

### Practice Points

#### Hand-held ultrasound

- Vscan ultrasound can be carried in physician's pockets and be used at the bedside.
- MobiUS is Toshiba smartphone based and has cellular and wireless connectivity for image sharing.
- It is predicted in the future that all medical students will receive an US probe when they begin school that connects to their smartphone and works with an ultrasound application.

#### Point-of-care testing

- Sexually transmitted infections, such as gonorrhea, chlamydia and HIV, can be tested for relatively rapidly at the bedside.
- An Android phone can be turned into a continuous glucose monitor by using the Dexcom glucose sensor with an application developed by Odyssey Computing.
- The high-sensitivity cardiac troponin assay will soon be available clinically in the USA.
- POC tests that detect biomarkers for both sepsis and traumatic brain injury are in development.

#### Smartphone ECG

- The AliveCor Heart Monitor can be attached to any smartphone and is similar to lead 1 of a 12-lead ECG. Also, by various placement of the device a 12-lead ECG can be obtained.

#### Video laryngoscopy

- The video laryngoscope is proven to be superior to direct laryngoscopy in difficult intubations.
- As their use becomes more widespread, it is predicted that they will replace direct laryngoscopy as the first-line intubation technique.

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The field of medicine today is evolving to bring care directly to the patient at the bedside. New technological advances have allowed for quicker diagnoses and, therefore, more efficient patient care. Bedside ultrasound has become more compact and portable so that it can fit in the pocket of a lab coat and transmit images over Wi-Fi networks. The availability of new and improved point-of-care testing has decreased the time between diagnosis and treatment. Non-traditional applications of the smartphone are increasingly expanding, and are being used to reach users in settings outside the hospital and clinic. In addition, the use of video laryngoscopy has become more of a first-line therapeutic tool for airway management at the bedside.

**Keywords:** bedside diagnostics • ECG • emergency medicinehand-heldultrasound  
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Over the past few decades, the numbers of tests and procedures that can be performed at the patient's bedside have notably

increased. This has important implications for both patients and physicians. Patients can receive a diagnosis and treatment in a more



**Figure 1. Vscan.**  
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timely manner when compared with waiting for laboratory results to come back. Physicians benefit from being able to deliver care in a more efficient manner. This results in better patient flow, which is especially important in an emergency room setting. In addition, bedside diagnostics decrease the amount of potentially unstable patients that have to be moved in order to receive imaging tests.

One tool, the smartphone, is revolutionizing medicine both in and out of the hospital setting. In 2013, 56% of adults owned a smartphone and those between the ages of 18–34 years had an ownership rate of approximately 80% [1]. This widespread use is being taken advantage of in healthcare as a platform to reach many people. There are hundreds of health-related applications that can be downloaded onto a smartphone and be used by physicians and nonphysicians alike. It should be noted, however, that not all of these applications are US FDA approved and should be utilized with appropriate caution. The smartphone is also increasingly being taken advantage of as a diagnostic tool in medicine.

This article focuses on discussing the recent advancements made in bedside diagnostic and therapeutic tools by highlighting important and relevant examples. For each example there will be a brief history and then a review of the current literature will be explored. Furthermore, limitations and future directions will be discussed. The studies described within this review article were obtained by searches

on PubMed and Google Scholar using relevant search terms.

### Hand-held ultrasound

Ultrasound (US) has been used in a variety of medical fields since the mid-1900s but it was not until the 1980s that machines became smaller, faster and more portable, and could be utilized in fields like emergency medicine and critical care [2]. In emergency medicine, exams are more focused on the current problem rather than a thorough exploration of the entire body. Therefore, the focused assessment with sonography for trauma (FAST) exam was created to specifically look for free fluid, especially blood, in the abdomen [3,4]. Two of the earliest studies of FAST exam utilization in the emergency department concluded that it is “a safe, rapid, and accurate screening technique in detection of hemoperitoneum in the patient with abdominal trauma” and that it “should become a standard procedure in emergency departments (EDs)” [5,6]. In addition to looking at the abdomen, the extended FAST exam can be used to evaluate the lungs and diagnose conditions such as a pneumothorax and pleural effusion [7]. In the intensive care unit portable US is a useful way to monitor changes in patients over time by doing repeat USs periodically. This also allows the patient to stay in the unit without having to be transported to radiology [8]. One field that has lagged behind in its use of portable US is pediatric emergency medicine. Currently, abdominal CT is the study of choice for stable pediatric patients with a suspected abdominal trauma injury, but this comes with the risk of exposure to potentially harmful ionizing radiation [9]. For this reason, there has recently been a shift toward utilization of the FAST exam in pediatric emergency departments.

The development of the hand-held US has allowed physicians to retain the uses of the portable US machine as well as expand its applications and take it virtually anywhere because of its even smaller size. Due to its increased portability, the pocket-sized US can potentially be used by personnel outside the hospital setting including paramedics, military medics and physicians in rural areas and developing world countries [3,10].

An area where hand-held US devices are gaining a lot of attention is their application in places where access to medical care and imaging is limited. Two major factors in the feasibility of this use include their small size and relatively low cost [11]. In addition, the transmission of images over a cellular or wireless connection would allow physicians, or even lower level practitioners, practicing in these settings to easily transmit images to highly trained radiologists many miles away for evaluation [12]. In this way telemedi-

cine, or more specifically teleultrasound, can eliminate the need for travel and reduce wait time for results [13].

### Vscan

Vscan is a small portable US system that was released in 2009 by the General Electric Company (Figure 1). Its price tag is in the range of US\$7000–8000 and its FDA cleared indications include: abdominal, cardiac, urology, fetal/OB, pediatric, selected peripheral vessels and thoracic/pleural motion and fluid detection. The device itself is palm-sized and has a probe that is connected to a cellular flip phone look alike, but it has no cellular or wireless connectivity [14].

Due to its small size, ease of use by a trained professional, and cost-effectiveness, the Vscan has potential applications in a wide variety of medical specialties at the bedside. In the field of internal medicine, one study examined the benefit of adding routine cardiac and abdominal US exams to patients admitted to a medical department. They found that by adding less than 10 min to their normal exam by performing US with a Vscan, the diagnosis was corrected in almost one out of every five patients [15]. Another study aimed to compare hand-carried US to contrast-enhanced multidetector CT (MDCT) in the diagnosis of free intra-abdominal fluid and organ lacerations in major trauma patients. The study concluded that a FAST exam with the hand-carried US was a “reliable and rapid alternative” to MDCT scans in these scenarios [16].

Cardiology and its incorporation of Vscan into everyday practice is currently a highly researched topic. The Vscan not only has a black and white imaging mode for looking at anatomy, but it also has a color-coded blood flow imaging mode [14]. There have been multiple studies comparing echocardiography exams with Vscan and the standard transthoracic echocardiogram (TTE). In the acute care setting, one study concluded that Vscan used by trained cardiologists has good diagnostic accuracy and is more practical than standard or even portable echocardiographs [17]. Another study suggested that Vscan could be the next-generation stethoscope, although more testing needs to be done to validate this claim [18].

In the field of obstetrics and gynecology, a transvaginal modification to the Vscan US has been developed. It is known as the Troyano transvaginal gadget probe (TTGP-2010) and a study conducted in Spain concluded that its detection capability was comparable to that of a high definition US device [19]. This application further demonstrates the potential versatility of the Vscan US in medicine.

In addition to providing care at the bedside, the Vscan device can be used in a variety of other point-of-care settings. For example, at the 2010 winter

Olympics in Vancouver (Canada), physicians had the Vscan available in the athlete’s village it was used by the emergency physicians and surgeons as a first-line diagnostic tool [20].

A search of “Vscan US” on ClinicalTrials.gov produces about a dozen results of ongoing or completed clinical trials. The general theme of the trials is to evaluate different applications of the Vscan. A couple of examples include: “Efficacy of Ultrasound to Guide Management During a Rapid Response Event” and “Estimation of Spleen Size with Hand Held Ultrasound” [21].

One of the major limitations of the Vscan US device is its lack of cellular or wireless image sharing. Images must be saved on the micro-SD card and then emailed to the recipient through a PC. To try and combat this, a group of physicians and PhDs used software to transfer uploaded echocardiographic PC images from a Vscan to a server and then to a smartphone. They showed that the interpretation of an echo on a smartphone was still accurate when compared with the original Vscan image [22]. There is also some literature that critiques the device, including one study that knocked the Vscan for having poorer resolution than the cart-based US (M-Turbo). For this reason the study suggested that perhaps, in an emergency room setting where the cart-based system is available, it should still be preferred over the hand-held device [23].

### MobiUS (Mobisante, WA, USA)

The MobiUS SP1 US system is newer than the Vscan and gained US FDA approval in 2011, becoming the



**Figure 2. MobiUS SP1.**

Reproduced with permission from Mobisante (WA, USA).



**Figure 3. AliveCor Heart Monitor.**

Reproduced with permission from AliveCor, Inc (CA, USA).

first smartphone-based US system (Figure 2). The device is a Windows Mobile 6.5-based Toshiba TG01 smartphone and requires a USB 2.0 port for the probe [24,25]. In contrast with the Vscan, MobiUS has both cellular and wireless connectivity. This allows images to be sent over these networks for diagnosis, second opinion, etc. The device also runs for less than US\$10,000, which keeps it affordable and is still much less than traditional US systems [24].

The MobiUS SP1 system has similar indications for use as the Vscan. A study published in 2012 used the MobiUS SP1 US system to evaluate the suprahyoid airway which may be used to predict difficult intubation. In comparison to the BK Medical Flex Focus 400 US system, the study found no statistical difference between the two when evaluating the mean diameter of the hyomental musculature. It was therefore concluded that the MobiUS system was able to gather clinically useful images in this application [26].

Due to the recent approval and release of the MobiUS SP1 US system there is limited literature available at this time. The device itself is limited because most smartphones, for example Apple's iPhone and Google's Android, do not support a 2.0 USB port, so currently the probe can only be used with the Toshiba smartphone provided.

### Future perspective

It is clear that hand-held US has tremendous potential to improve many aspects of medicine. In just a few short years it has evolved to a smartphone-based system that can transmit images over Wi-Fi networks. The next step in its evolution is to make the probe compatible with iPhone and Android smartphones. Either the smartphones could adopt a 2.0 USB port into their design or an adaptor could be created for the probe that would allow it to work with current smartphone capabilities.

In 2012, the Icahn School of Medicine at Mount Sinai (NY, USA) began giving all first year medical students a Vscan device as part of a research project to show its benefit to medical education [27]. It is predicted

that in the near future all medical students will receive an US probe that connects to their smartphone when they begin school. They would be able to simply open an app and turn their smartphone into a hand-held US. It would be ideal if these images could then be stored on a cloud and be accessible for review by students and physicians. This would allow medical students to be very comfortable with US by the time they reach residency and be able to apply it to which ever field they choose.

### Point-of-care testing

Point-of-care (POC) testing emerged in the 1980s in critical care settings where whole-blood analysis began being used to obtain rapid results within 2–5 min [28]. In order to be considered a true POC test, there are some essential features that they must possess. Some of these include: the use of minimally invasive samples (fingerstick whole-blood or saliva), easy to perform and interpret by personnel with minimal scientific training, use across a wide range of temperatures, have extended shelf life, and use without requiring additional equipment if possible [29]. POC testing has a short turnaround time when compared with laboratory tests, which allows for quicker diagnosis and treatment. This results in improvement in patient outcomes, especially in fields such as emergency medicine and critical care where time is of the essence.

In emergency medicine, knowing the pregnancy status of a female is necessary before many imaging tests can be done and drugs can be given. Historically, this test has been done with a serum or urine sample. There can be problems or delays in obtaining these samples, so a human chorionic gonadotropin (hCG) test that uses a drop of whole-blood is ideal. Recently, one study showed that the same rapid hCG immunoassay kit (Beckman Coulter ICON 25 rapid hCG immunoassay kit) used for serum and urine could be accurately used with whole-blood [30]. Advancements similar to this one continue to improve bedside diagnostics and patient care.

### iSTAT analyzer

The iSTAT analyzer made by Abbot Point of Care (NJ, USA) has been available in acute care settings for over 15 years with routine electrolyte testing. Over the years it has expanded to include 18 cartridges that perform a variety of tests that include: chemistries/electrolytes, hematologic, blood gases, coagulation and cardiac markers. The iSTAT is portable, lightweight and easy to use. The newer model is wireless and can transmit results directly to the electronic medical records (EMR) [31]. Literature attempting to evaluate the iSTAT in comparison with traditional laboratory tests



is available. Physicians from the department of pathology at Massachusetts General Hospital compared the iSTAT prothrombin time/international normalized ratio (PT/INR) cartridge with the MDAII coagulation analyzer in a central laboratory and found they compare well [32].

### STI testing

The development of POC testing for the diagnosis of STIs is important because delays can result in serious complications and further spread of infection. This is especially important in areas of the world where there is limited access to pathology services or remote places where results could take substantially longer because of travel time. Another important issue that rapid POC testing addresses is the lack of follow-up when tests need to be sent out to a laboratory and are not available that day. For example, in the emergency department, a patient may receive STI testing but never come back to get their results or appropriate treatment. If results are available the same day the patient is more likely to get treatment and this will help prevent the spread of disease.

Rapid HIV testing at the bedside is becoming common practice. In the emergency department, every patient is asked whether or not they would like to be tested for HIV. The standard methods of HIV testing can take several days while the rapid test can deliver results in 20 minutes. The rapid tests detect HIV antibodies and specimens can be oral fluid, plasma, fingerstick or venipuncture whole blood [33]. POC HIV testing is recommended for anyone in a high risk population group.

According to the Centers for Disease Control, chlamydia (CT) and gonorrhea (NG) are the most prevalent of all reportable STIs and CT is the most commonly reported STI in the USA [34]. These two infections are notorious for presenting with minimal symptoms and causing serious complications, such as pelvic inflammatory disease in females. A bacterial culture that needs to be sent to a laboratory can take a few days to get results. In early 2014, a pilot study was published that used the BioStar Optical Immunoassay to detect NG in men attending a sexual health clinic. When compared with nucleic acid amplification testing it was concluded that “in principle POC testing for diagnosing NG is achievable” [35]. On June 23rd 2014 another study on this topic was published out of Australia. This study used the Xpert CT/NG assay (Cepheid) for diagnosis. This assay can detect and differentiate between CT and NG with high sensitivity and specificity in 90 min [36]. The goal of this study was not to compare the Xpert to another device but to explore the clinical implications of using this POC test

in remote settings. The findings of this study, which include advantages and limitations, hope to inform guidelines related to the implementation of CT/NG POC testing [37].

### Continuous glucose monitoring

Currently, there are many different models of continuous glucose monitors. Most of them have a sensor that sends information to a specific receiver developed by that company. Three examples include the FreeStyle Navigator, Dexcom and the Guardian Real-time GCM System [38–40]. These devices have real-time glucose readings every 1–5 minutes and can warn the patient if they are developing hyper or hypoglycemia [41]. The Dexcom glucose sensor can also be used with an Android phone using an app developed by Odyssey Computing. The sensor communicates with the smartphone over an ANT+ radio signal [42]. The ultimate goal would be to develop a sensor that is linked to a glucose pump which can give the correct amount of insulin needed to maintain optimal blood glucose levels in a closed loop system. A limitation of this type of system would be the sudden development of life-threatening hyper or hypoglycemia if the device malfunctioned.

Innovations in the monitoring of blood glucose for diabetic patients can benefit both patients and physicians. For patients, continuous glucose monitoring (GCM) allows them to see trends in their blood glucose and what triggers spikes so they can better manage their diabetes. GCM can also be used to communicate readings with physicians to allow them to better manage their patients. In critically ill patients in the emergency department or intensive care unit, glucose control is very important in their management. Critically ill patients often have hyperglycemia, which can be associ-



**Figure 4. GlideScope.**  
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ated with worse outcomes. On the other hand, intense glucose control can expose patients to hypoglycemia, which is also associated with increased mortality [43]. It is thought that if continuous glucose monitoring can be utilized at the bedside it can improve glucose control for critically ill patients.

### Future perspective

POC testing is a rapidly evolving field as more reliable tests are being developed that could potentially reduce the need for lengthy laboratory evaluation. The use of these tests will continue to expand in the field of emergency medicine, as well as become common practice in others.

The high-sensitivity cardiac troponin assay is a test that is not yet available in the USA clinically, but should be very soon [44]. In Europe, this assay is already being used as a diagnostic method of ischemic heart disease. The increased sensitivity would potentially allow for an earlier diagnosis of acute myocardial infarction and subsequent intervention [45]. Although, if the test is too sensitive it could inappropriately increase hospital admissions.

In addition, there is enthusiasm for POC tests that detect biomarkers specific for sepsis and traumatic brain injury [46,47]. These tests are in early development, but if they are shown to be useful clinically they will be of tremendous benefit to patients suffering from these conditions.

### Smartphone ECG

In December 2012, the AliveCor Heart Monitor (AliveCor; USA) gained FDA approval (Figure 3). The device is approximately US\$200 and the attachment is compatible with any smartphone. Once the app is downloaded, an ECG can be recorded in less than a minute, saved and uploaded securely to a cloud. Results can then be viewed, emailed, and printed in a PDF format [48].

### Rhythm

The AliveCor Heart Monitor is equivalent to lead I of a standard 12-lead ECG. The electrodes can be held with fingertips or placed on the chest to obtain a reading. The main purpose of the device is to detect arrhythmias such as atrial fibrillation (AF) [48]. One study compared the accuracy of the AliveCor iPhone ECG with the 12-lead ECG read by a cardiologist in the detection of AF. It was concluded that the iPhone ECG performed very well and is ideal for community screening [49].

### Acute ischemia

When it comes to detecting ischemic changes, a full 12-lead ECG is required. AliveCor acknowledges that

their device is not meant to be a replacement for a 12-lead ECG; however, by various placement of the device, the equivalent of a 12-lead can be obtained in austere environments.

### Future perspective

The smartphone ECG can be very useful for people with diagnosed heart conditions and those who are health conscious. It also has the potential to be used in remote locations and places like airplanes where there are no other options available, then care can be redirected if needed. With the increasing number of people that own smartphones, it is expected that devices such as this one will gain more widespread use as well.

### Video laryngoscopy

Laryngoscopy was introduced around the turn of the 20th century. It was originally developed for use in otolaryngology but advances in the field of anesthesiology established a need for endotracheal intubation (ETT) in the operating room [50]. The two laryngoscopes that dominate the field of direct laryngoscopy today include the Miller blade and the Macintosh blade. The Miller blade, developed in 1941, is a straight blade and was the first to pick up the epiglottis [50,51]. In 1943, the Macintosh blade was developed, which has a continuous curve and lessens the chance of damage to the upper teeth [51]. The goal of direct laryngoscopy is to manipulate the airway to align the oral, pharyngeal and tracheal axes in order to visualize the vocal cords. This can be difficult to do in certain situations and as a result there is frequent failure of direct laryngoscopy.

In 2001, the first commercially available video laryngoscope came on the market to improve the failure rate of direct laryngoscopy. Video laryngoscopy is considered an indirect method because the vocal cords are visualized on a screen rather than in first-hand view. These scopes can look around the curve of the airway with less need for movement, which results in less stress and trauma to the patient [52]. Today, there are many different models of video laryngoscopes and their use has expanded outside the operating room to emergency departments and critical care settings at the bedside.

### Available models & comparisons

Some examples of video laryngoscopes include the GlideScope (Verathon Inc, WA, USA) (Figure 4), Pentax Airway Scope, McGrath Video Laryngoscope, and the C-MAC Video Laryngoscope. The various models have slightly different specifications but in the end they all serve a common purpose. The GlideScope has a 60° angulation of the blade, which helps to improve the view of the glottis. There is also a heating mechanism

that prevents fogging to maintain a clear image even in difficult intubations [53]. In trauma victims with a possible cervical spine injury, the GlideScope reduces movements during intubation and may reduce the risk of secondary damage [54]. The GlideScope is also a very useful teaching tool because the image is displayed on an easy to view monitor on a mobile stand [55].

The latter three models all have the video monitor directly on the handle. This allows them to be more portable than the GlideScope, especially in settings outside the hospital. The McGrath Video Laryngoscope was the first fully portable model that could be taken virtually anywhere [56]. The Pentax Airway Scope has a built in guide channel that directs the ETT toward the glottis. There is also a built in channel for suction catheters allowing aspiration of fluids if needed [55,57]. Lastly, the C-MAC Video Laryngoscope is the well-known Macintosh blade with a video unit added on. Therefore, this laryngoscope can be used in both direct and indirect intubations [55,58]. In a comparison study, experienced anesthetists rated the C-MAC as the easiest to use, possibly because of familiarity with the blade [59].

When compared with direct laryngoscopy, multiple studies have shown that video laryngoscopy improves glottic view and increases first-attempt success rate [60,61]. It has also been shown that the success rate of ETT can be increased with a video-assisted device when used by people with no or only minimal experience [61].

### Difficult intubation

With the expansion of laryngoscopy use outside the controlled environment of the operating room came an increased incidence of difficult intubations. In emergency airway management settings there can be anywhere from 10 to 22% more difficult intubations, with an increased risk of respiratory and hemodynamic complications, and even death [62]. Some difficult airway predictors include: obesity, large tongue, cervical immobility, blood, vomit, airway edema, and facial or neck trauma. In the emergency department, several studies have concluded that video laryngoscopy is superior to direct laryngoscopy in difficult airway situations [63,64]. A 2014 study has recommended video

laryngoscopy be the “primary intubating device for patients with predicted difficult airways in the ED” [65]. However, there are situations where video laryngoscopy may be difficult due to excessive bleeding or vomit that obstructs the camera. For this reason, it remains necessary that physicians be proficient in both direct and indirect methods of laryngoscopy as well as other failed airway techniques.

If failed intubation occurs with a difficult airway in the ED, the gum elastic bougie (GEB) can be used as a rescue airway device [66]. The GEB can be used with both direct and indirect laryngoscopes, although if used with an indirect device, it needs to be curved at a similar angle.

### Future perspective

While laryngoscopy, both direct and indirect, has been utilized by anesthesiologists in the operating room for a while, it is a technique that has more recently moved to emergency and critical care settings. As a result, there is substantially more literature available on the use of these devices in anesthesia versus emergency and critical care medicine. In a 2013 survey given to program directors of critical care fellowships, 89% reported they have an available video laryngoscope, but it was only used as the primary device in 16% of the programs that responded [67]. As video laryngoscopes become more widely used and more literature becomes available, it is predicted that they will soon replace direct laryngoscopy as the first-line intubation technique in emergency and critical care medicine.

### Financial & competing interests disclosure

JVK Jehle is also a Professor of Emergency Medicine and an Attending ED Physician and Board Member at: Department of Emergency Medicine, Erie County Medical Center, State University of New York at Buffalo, NY, USA. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

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