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Emerging Technology Review

Handheld Point-of-Care Ultrasound Probes: The New Generation of POCUS

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Recent advances in ultrasound technology have made ultrasound equipment more versatile, portable, and accessible than ever. Modern handheld, ultra-portable ultrasound devices have been developed by multiple companies and are contributing to make bedside ultrasound evaluation a practice available to all physicians. The significance of making point-of-care ultrasound (POCUS) a common practice that all physicians eventually can use in the evaluation of their patients is changing the way medicine is practiced, allowing physicians to quickly obtain valuable information to complement the traditional physical examination. Despite the proven benefits of using bedside ultrasound imaging as a part of the patient evaluation and for procedure guidance, adoption of this technology still is not widespread among anesthesiology clinicians nor is there uniform teaching of ultrasound skills to anesthesia residents and faculty. Among obstacles that have been identified as precluding achievement of the goal of widespread utilization of POCUS among anesthesia professionals and trainees, are the availability of equipment for all physicians when it is needed and lack of instructor supervision for trainees who desire to use ultrasound but do not always have an instructor knowledgeable in POCUS with them when an ultrasound examination is warranted. Herein, the characteristics, advantages, and limitations of available ultra-portable, handheld ultrasound devices are analyzed, with a focus on the Butterfly iQ (Butterfly Network, Inc, Guilford, CT) pocket probe, which is available at the authors' institution, and how some of its features, such as the capacity to emulate multiple transducers and its cloud-sharing and teleguidance technology, may contribute to increase the availability and use of POCUS by anesthesia clinicians.

Key Words: anesthesia; ultrasound; echocardiography; point-of-care ultrasound; POCUS

POINT-of-care ultrasound (POCUS) is used routinely in the perioperative and intensive care settings for rapid hemodynamic and respiratory assessment.[1-3] In addition to expediting the diagnosis of acute pathologies, POCUS can be useful in multiple other situations, such as focused management of perioperative hemodynamic instability and assessment of fluid status and lung pathologies, to name a few.[4] Multiple professional organizations have endorsed the perioperative use of POCUS and have recommended that proficiency in various aspects of POCUS should be incorporated into residency training. Despite this appreciation of its value, proficiency in POCUS is not a mandated milestone during anesthesia residency training, with significant variation in trainee exposure to ultrasound education.[5]

Fiscal constraints and equipment cost have been the major limitations in the widespread availability of ultrasound machines, and even though POCUS educational courses are available, these are intermittent and do not provide real-time or continuous instructor-trainee interaction outside the course. Perioperative use of ultrasound requires real-time image acquisition, interpretation, and modification of therapy based on interpretation. Concerns over lack of adequate supervision for POCUS during emergency clinical situations also have precluded the routine use of POCUS. Multiple handheld ultrasound systems are commercially available that cost only a fraction of the cost of the traditional ultrasound systems.

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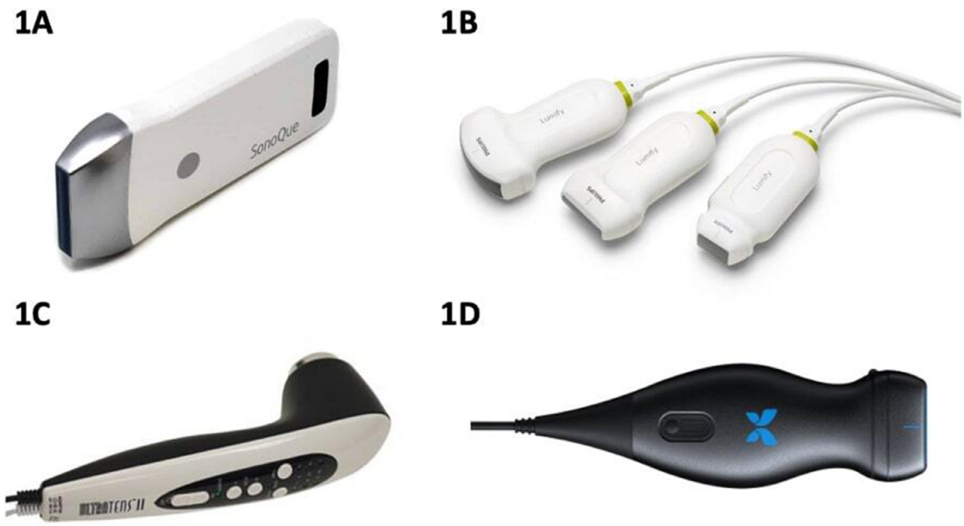

Fig 1. Commercially available portable ultrasound pocket probes. (A) SonoQue portable, wireless, linear probe (SonoQue, Yorba Linda, CA). (B) Lumify curved, linear, and phased-array probes (Philips, Amsterdam, Netherlands). (C) UltraTENS II portable ultrasound probe (TENS Pros, St Louis, MO). (D) Butterfly iQ (Butterfly Network, Inc, Guilford, CT).

However, their initial cost is still upwards of $8,000 to $10,000, and they have only local storage for acquired images. With increasing bandwidth and encryption of the networks, remote real-time expert consultation can be performed on patient data that is compliant with federal privacy laws. In this article, the available technologies for image acquisition, remote interpretation, and the authors' initial experience with a handheld ultrasound system for POCUS are reviewed.

Breaking Down Barriers to POCUS Training

Even though ultrasound education has been possible through familiarization with standalone machines and practice in a fixed location, few methods allow for combined mobility and continued on-the-job training in competency development. Ultrasound courses often are introduced in stages, starting with understanding basic machine operation and ultrasound physics, the acquisition of a variety of anatomic views, and finally practice using simulators and/or real-life models.[6] Even though the benefit of a single-location POCUS course is proven, scheduling the courses and maximizing faculty participation can be a logistical challenge. A recent study demonstrated that only 26% of faculty in a large academic institution could be trained adequately in the use of POCUS through online resources and individualized proctored training because of challenges in scheduling of classes around clinical and nonclinical duties.[7] Clearly, the use of alternative teaching methods for successful implementation of POCUS is required.

The recent commercial availability of "pocket, or handheld, probes" has made POCUS more readily available. Their web-based operation and internet connectivity can facilitate the introduction of remote learning and training programs that can incorporate on-the-job assessment of competency. Remote teaching and image review capabilities also serve to promote

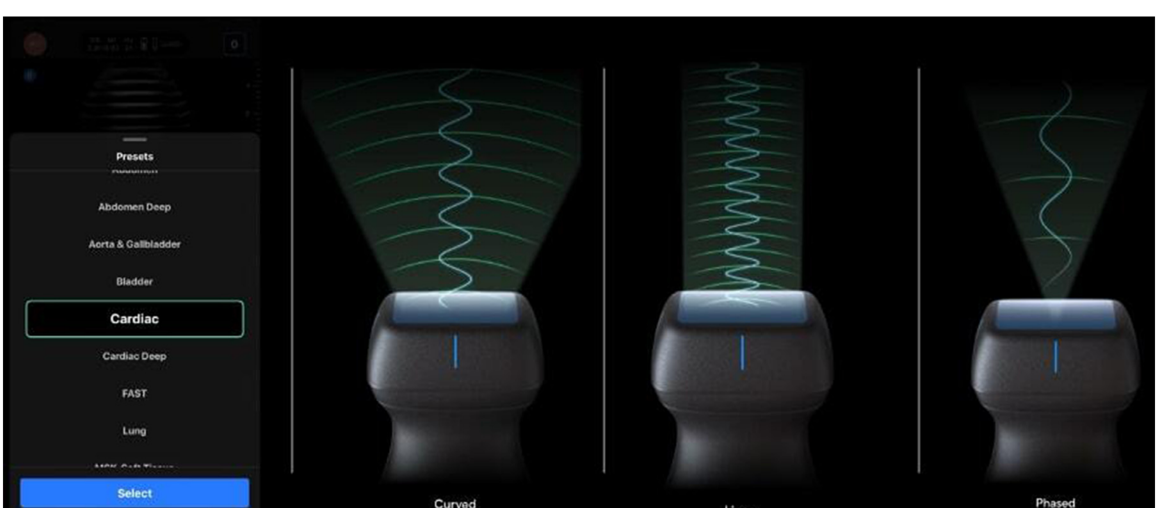

Fig 2. Multiple presets are available within the application that will adjust the frequency of the probe between 1 and 5 MHz, which makes the probe capable of emulating a curved, linear, or phased-array transducer.

quality assurance and reassurance without the need for direct supervision when bridging the gap between initial POCUS training and the development and monitoring of proficiency. Besides low initial cost and maintenance, these pocket probes offer telecommunication over a cloud-based platform for remote viewing of acquired images to allow for distant peer evaluation of acquired images. Such pocket probes include those manufactured by SonoQue (Yorba Linda, CA); Philips (Amsterdam, The Netherlands); TENS Pros (St Louis, MO); and Butterfly Network, Inc (Guilford, CT) (Fig 1). The authors' institution has invested in the Butterfly iQ (Butterfly Network) for implementation of routine perioperative POCUS and faculty and resident education. In the present review, the technical aspects, performance details, and limitations associated with these types of devices, with a focus on the Butterfly iQ pocket probe, are discussed.

Probe Description

The term "pocket probe" refers to a readily available, portable, lightweight, affordable, and easy-to-use ultrasound probe. In order to reduce costs and complexity, manufacturers have incorporated technologic innovations, foregoing the traditional use of piezoelectric crystals. Instead, a novel ultrasound-on-chip technology method is used that incorporates a 2-dimensional array of 9,000 micro sensors capable of emulating curved, linear, and phased-array transducers over a frequency range of 1- to- 5 MHz. This technology is unique and strays away from the traditional piezoelectric crystals used in probes for image acquisition that are costly and require separate probes for low- and high-frequency analysis. This technology uses a capacitive micromachined ultrasound transducer that generates voltage through a membrane that sends ultrasonic waves into the region of interest. In addition, the ultrasound-on-chip technology bypasses some of the more traditional connectivity in piezoelectric probes between the probe and displays, allowing for the image to be displayed on a mobile device, thus reducing the cost again and further increasing portability.

Device and Application Description

- Although software options may vary among devices and manufacturers, pocket probes are available for use with both Macintosh, Windows-Based Operating Systems, and mobile devices with IOS or Android software.
- Examination-specific presets also are available to optimize the depth and frequency of the probe for organ-specific examination. The probe is capable of emulating multiple types of transducer (eg, curved, linear, and phased-array) based on the preset that is selected (Fig 2). For example, in a lung preset, a high-frequency linear format is optimized in the near field for visualization of pleural sliding, and as the depth is increased, the frequency range changes automatically in order to support deeper interrogation for A- and B-lines.

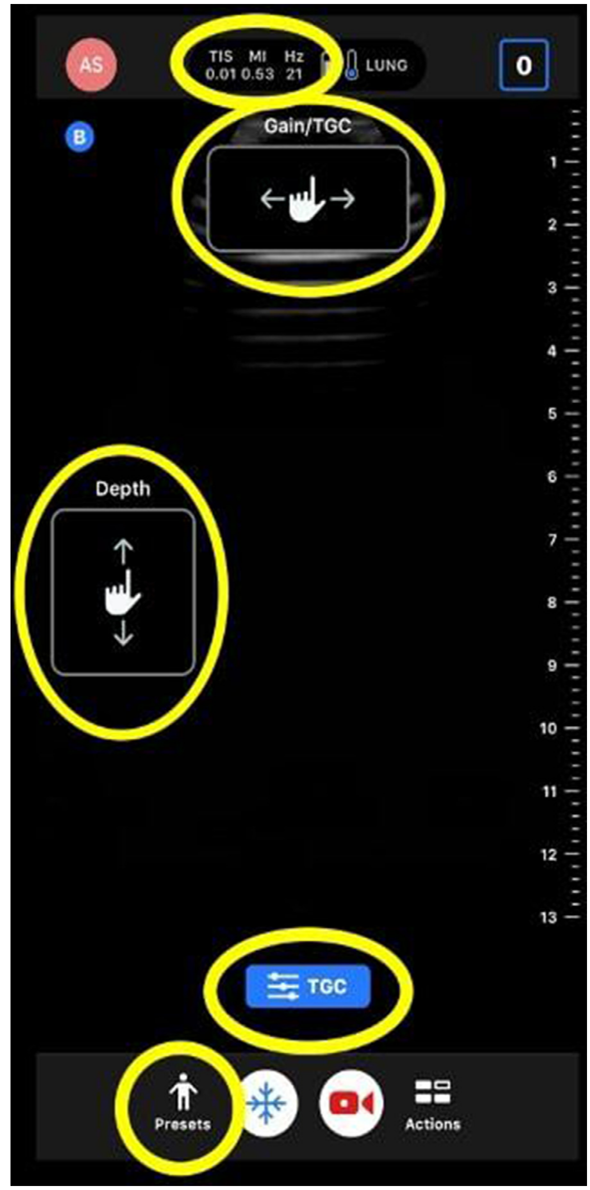

Fig 3. Selection of on-screen controls to optimize the image. These include a selection of presets that will modify the frequency and type of probe to be emulated and control for depth, gain, and time gain compensation. The thermal index and mechanical index can be monitored throughout the examination to ensure patient safety.

- After a preset has been selected, the user can use the touch screen controls to make additional modifications to optimize the image, including gain, time gain compensation, and depth (Fig 3).
- Multiple supplemental imaging tools also can be activated using the touch screen controls to aid in anatomic and pathologic identification. These advanced imaging tools include M-mode, color-flow Doppler, and power Doppler (Fig 4).
- In addition to imaging, the pocket probe devices also possess the following advanced features:
  - Ability to record images and upload them to a wireless server
  - Linear measurements

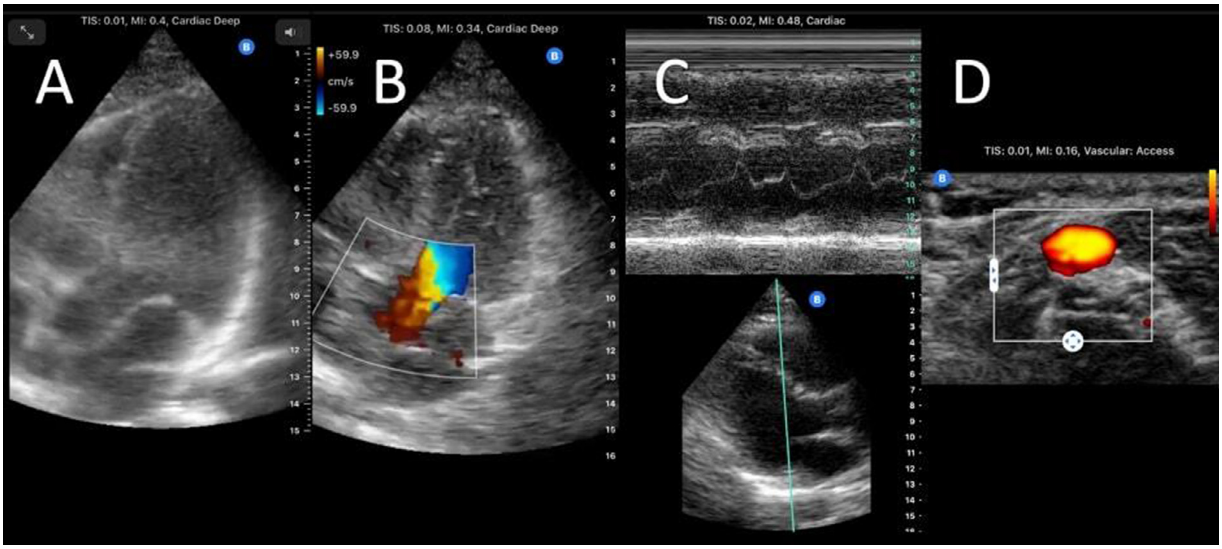

Fig 4. Various imaging modes that are available on the Butterfly iQ include (A) B-mode or 2-dimensional mode, (B) color flow Doppler, (C) M-mode, and (D) power mode.

  - Labeling of anatomic structures
  - Midline marker to assist in procedural guidance
  - Semiautomated dynamic tracking for automatic estimation of ejection fraction
- The system output can be adjusted manually to limit ultrasound exposure, and the thermal and mechanical indices are displayed in real time for the operator to use the ultrasound in a safe manner.

Image Storage

In addition to the local server upload, many of these devices possess the ability to synchronize and upload the images to a web-based cloud server in a Health Insurance and Portability Accountability Act−compliant fashion (Fig 5). Depending on the availability and bandwidth of the internet, image upload is in real time and instantaneous and thus raises the possibility of providing remote, real-time feedback to the operator, expert interpretation, and consultation. This feature is not only useful for remote medical diagnoses and image interpretation in underserved areas, but also in providing a continuous trainee-instructor interaction. In terms of teaching, this cloud platform also allows for remote quality assurance of images obtained by trainees for continuous evaluation and teaching.

Artificial Intelligence and Augmented Reality

Two other newer features that are available on specific devices and have promising potential are the use of artificial intelligence (AI) to help optimize image quality and the use of augmented reality (AR) to provide real-time teleguidance on procedural performance and image interpretation. The AI feature helps users with image acquisition by providing real-time feedback on the quality of their images to increase the chance of obtaining diagnostically relevant images. This aims to ensure that images captured are consistent and easy to obtain for novices while removing operator variability (Fig 6). The AR feature allows for remote teleguidance to allow a novice user to be in direct contact with an expert who is able to remotely guide the novice on correct probe placement and manipulation to obtain adequate images while also aiding in image interpretation (Fig 7). This feature is of particular value in performing POCUS examinations on patients with transmissible diseases, such as coronavirus disease-2019, because it allows 1 operator to perform the examination while multiple clinicians view the study being performed in real time without being exposed to the patient. Remote education and telemedicine are other areas in which this technology can be used.

Limitations

Although there are multiple advantages to the use and incorporation of portable ultrasound probes, there also are certain limitations with their use, including the following:

- These devices are not designed for prolonged imaging. Depending on the imaging modality, the temperature rises with 15- to- 20 minutes of continuous imaging, and the automatic cooling feature of the device is activated to freeze all imaging until the device has cooled down.
- Image quality with these pocket probes also has been described as slightly inferior to standalone ultrasound machines, but in the authors' experience, the images obtained are perfectly adequate for POCUS. The function of these probes is not to perform a comprehensive examination but to perform a focused examination sufficient for identifying acute pathologies, and the image quality obtained with these pocket probes is perfectly adequate for this function.

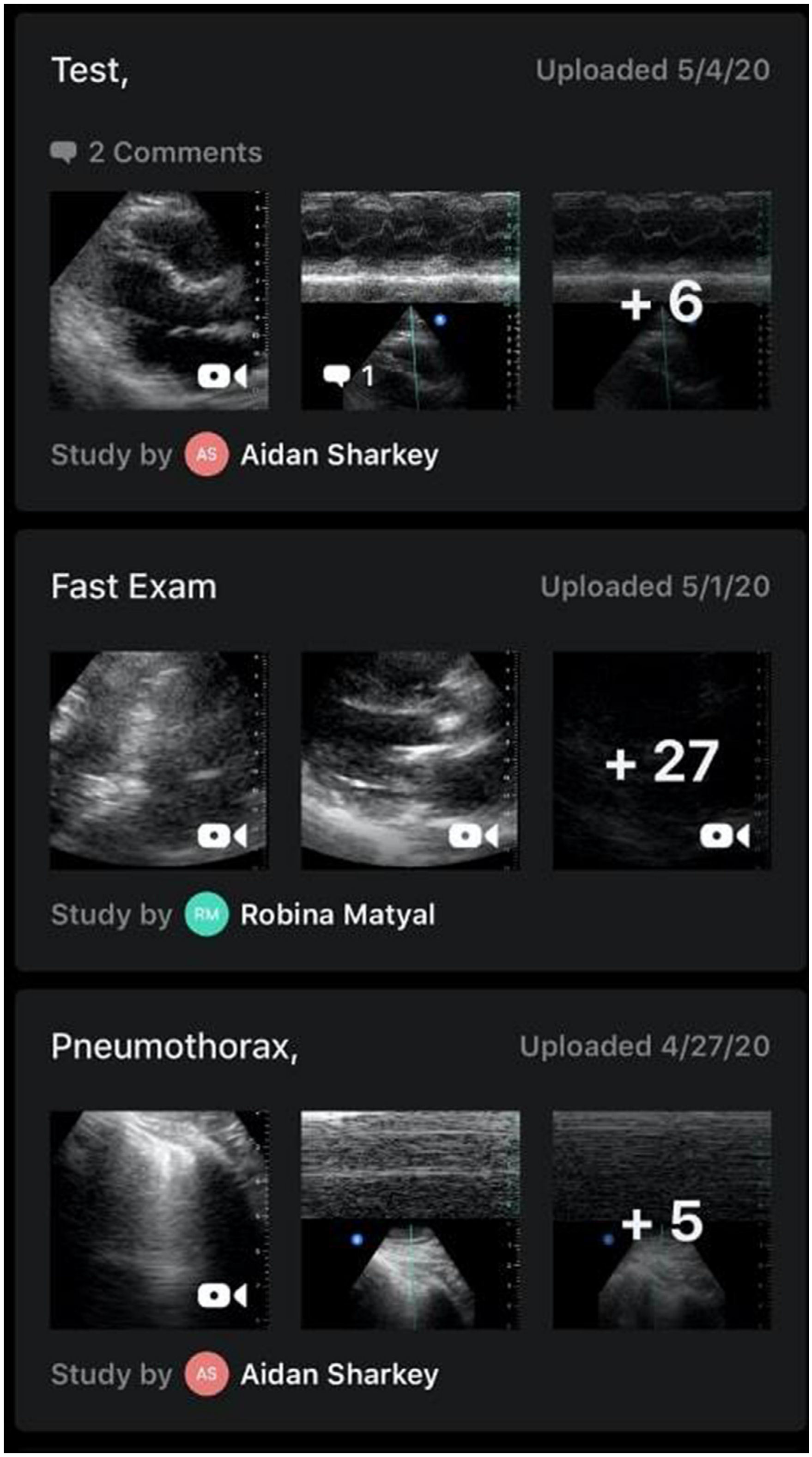

Fig 5. A Health Insurance Portability and Accountability Act−compliant cloud server is available within the application to upload studies that then can be shared among other users within an organization to facilitate remote consultation and peer review of images obtained by trainees. Comments can be made within the study to highlight salient learning points.

- A key function that is absent from some of these probes is the ability to perform spectral Doppler, which is paramount in diagnosing and quantifying valvular pathology. This feature is required for POCUS examinations in the authors' view, and software updates are expected in the near future that will address this issue and allow for spectral Doppler examination.

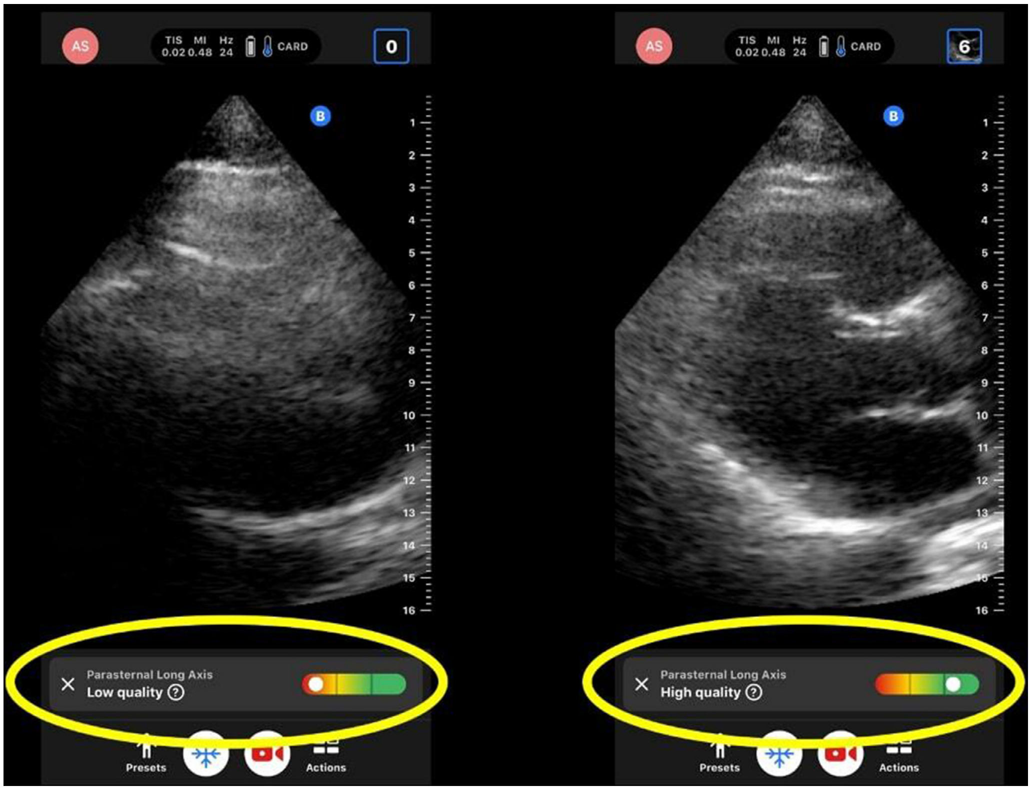

Fig 6. Artificial intelligence software within the application determines the quality of the obtained image by the user. This application ensures diagnostically relevant images are obtained by giving real-time feedback to the user.

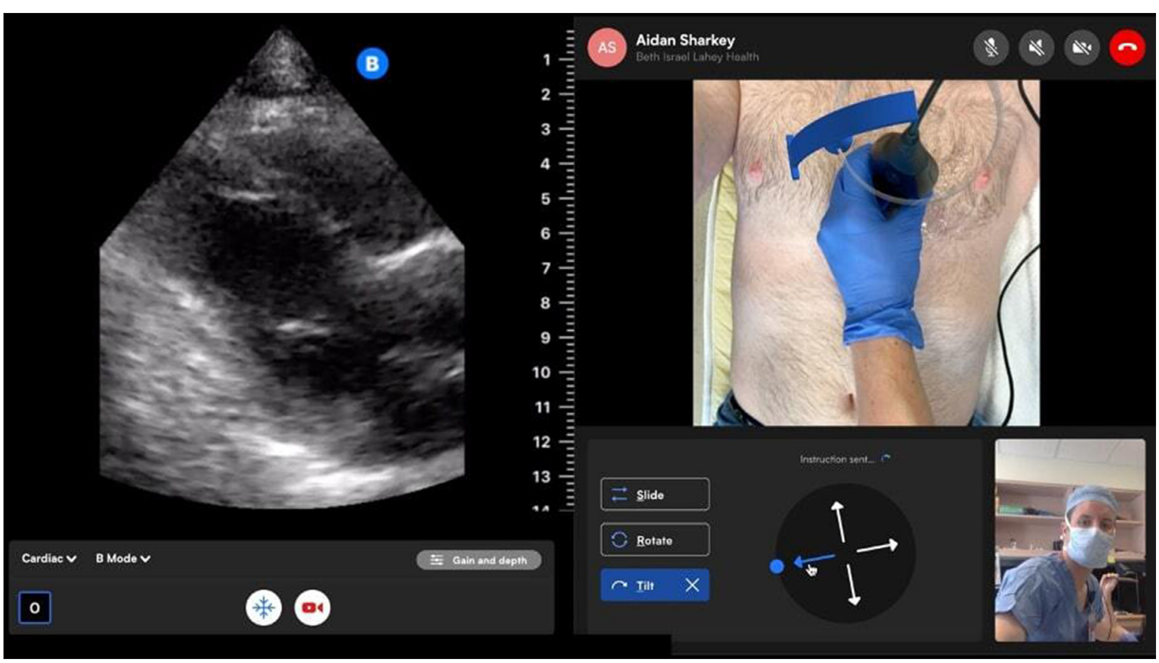

Fig 7. Teleguidance feature to facilitate remote collaboration with other users. The caller's ultrasound image and camera view are live-streamed to the collaborator, and there is 2-way audio and video communication to allow for real-time interaction. The collaborator can send graphical instructions that are overlaid directly on the Butterfly iQ application so the caller can be guided to the right view. The collaborator also can adjust the preset, mode, gain, and depth and can capture images or cines.

- Battery life for the currently available POCUS systems is limited but still ranges from 2- to- 3 hours in the majority of the systems and up to 5.5 hours in 1 pocket probe.
- Cloud storage of acquired images is almost mandatory because images on which clinical decisions are based need to be archived for future reference. Subscription to this

Fig 8. Customized storage cabinet in the authors' preoperative holding area to allow for rapid access to probes while keeping the probes in a safe environment and adequately charged for regular use.

service adds an additional monthly fee for users, which over time may be costly.

- Finally, even though the portability of these devices is a clear advantage, it also can be a disadvantage because the devices can be lost easily if proper care and attention are not undertaken with their use. The authors' institution has a specific standalone cart for the storage and charging of portable ultrasound probes. At any point in the day, the probes can be signed out by residents and faculty for use, and this creates accountability for their return while also ensuring and maintaining a constant charge (Fig 8).

Conclusion

The value of handheld ultrasound probes lies in their portability, cloud-sharing access, and telemedicine capability. These features have the ability to improve patient care in the perioperative period and faculty and resident POCUS education. The ability to transport a pocket-sized probe that is capable of changing from curved to linear image acquisition and from low-to high-frequency imaging is of particular value to the physician. Some of the current barriers to routine POCUS implementation into clinical care and education are broken down by this new technology. Machine availability, portability, cost, remote viewing, and telemedicine are no longer barriers to POCUS. Through the use of AI and AR, both novices and experts are able to acquire and interpret images, which will lead to faster diagnosis, focused clinical care, and better clinical decision- making. The introduction of POCUS into daily practice is no longer a possibility but a certainty, and these handheld ultrasound devices will be crucial to its implementation.

Correct rollout and implementation of POCUS are critical for its success moving forward. Future studies need to be undertaken to determine how to best implement POCUS into routine perioperative clinical care and how to educate both residents and faculty within departments. The use of a cloud platform, along with AI and AR, are new dimensions in clinical medicine, and clinicians need to determine how best to use these for optimal patient care and staff training. The authors' institution currently is developing a new POCUS curriculum that incorporates the new developments in handheld ultrasound technology, and the authors hope to be able to answer some of the questions surrounding POCUS through additional investigation. Studies the authors are undertaking simultaneously include evaluating the ways in which POCUS changes clinical management in the perioperative setting, along with proficiency and competency outcomes when remote learning is incorporated into the POCUS curriculum. Even though clinical history and physical examination currently are considered the standard of care for perioperative evaluation of surgical patients, it is only a matter of time before a focused POCUS examination also becomes a standard of care.

Conflict of Interest

None.

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