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# CMUT/CMOS-based Butterfly iQ – A Portable Personal Sonoscope

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**Abstract:** With the development of bioengineering technologies, medical ultrasound systems have evolved and advanced over the years, including the transition of ultrasound machines from analog devices to digital systems and improvements in transducer assembly from piezoelectric ceramics to single crystals. In the past several years, the further miniaturization of ultrasound units has become possible with the advancement of computer chip manufacturing and production. Most recently, a new handheld ultrasound system has been developed by the startup company Butterfly Network, using an innovative CMUT/CMOS-based probe technique. This paper will review the history, technology and features of this new device, as well as discuss its future potential as a personal sonoscope.

**Key words:** Handheld; Butterfly iQ; CMUT/CMOS technique; Ultrasound; Transducer

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**D**iagnostic ultrasound is a first line imaging modality for many clinical applications, given its advantages including high resolution, ease-of-use, lack of radiation, and cost effectiveness. Through the development of microelectronics and digital processing, miniaturized ultrasound devices have emerged and attracted both industrial developers and medical practitioners. As these new small and portable ultrasound units have become more widely available and easier to use, the role of ultrasound in the healthcare setting has evolved accordingly and has gained increasing popularity in clinical specialties such as emergency medicine, anesthesiology, intensive care, OB/GYN, and even general practitioners.

Several handheld ultrasound devices have been developed by ultrasound manufactures and approved for clinical applications. These miniature ultrasound units include the Vscan device (General Electric, USA), the Lumify system (Philips, USA), the Clarius wireless scanner (Clarius, Burnaby, Canada) and SonoStar wireless devices (SonoStar Technologies, Guangzhou, China), all of which have been approved by the FDA for

clinical use (Table 1). More information and description of these products can be founded in a review article by Yu et al [1]. More recently, a new handheld ultrasound unit, known as the Butterfly iQ, has been developed by a startup company using innovative CMUT/CMOS-based probe technology. This paper will review its unique history, innovative technique, clinical features, and future applications as a personal sonoscope.

## History of the Butterfly iQ

The Butterfly iQ handheld ultrasound scanner is the product of Butterfly Network, a Connecticut-based company founded in 2011 by Jonathan Rothberg, an engineer and entrepreneur who was previously best known as a pioneer in high-speed, massively parallel (Next-Gen) DNA sequencing [2]. His work in the field of Next-Gen sequencing is particularly notable for the invention of semiconductor chip-based DNA sequencing, a critical step towards the development of cheaper and more compact sequencing devices [3]. Rothberg has since focused on extending semiconductor-based

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technology to novel applications and technologies in healthcare. He has stated that he was inspired to bring his expertise in semiconductors chip-based technology to ultrasound by his daughter, who has tuberous sclerosis, a genetic condition that has required her to receive frequent ultrasound scans of her kidneys [4]. In 2017, the Butterfly Network received FDA clearance to bring the Butterfly iQ device to market for 13 different clinical applications, including peripheral vascular, small organs (including thyroid), cardiac, abdominal, urological,

fetal/obstetric, gynecological, and musculoskeletal ultrasound imaging in adult and pediatric patients [5]. In 2018, Butterfly Network was reported to have raised 250 million USD from large private investors, including the Bill and Melinda Gates Foundation and the Chinese pharmaceutical company Fosun Pharma. The company began shipping units in 2018 in the US, with plans to roll out in the European market in 2019 and the Chinese market by 2020 [6].

**Table 1** List of portable handheld ultrasound systems with features

Name	Probes	Imaging modes	Transducer	Link	Company
Vscan	dual heads	2D, CDI	piezoelectric ceramics	cable	GE Healthcare, USA
Lumify	S4-1 phased, C5-2 curved, L12-4 linear	2D, M, CDI	piezoelectric ceramics	cable	Philips, USA
Clarius	C3 Convex, L7 linear, C7 Microconvex, EndoEC7	2D, M, CDI, PDI, PW, PDI	piezoelectric ceramics	wireless	Clarius, CA
SonoStar	L6C, C6C, Dual heads C5DC, L5P, C5, C5D	2D, M, PW, PDI, CDI	piezoelectric ceramics	wireless	SonoStar, China
Butterfly iQ	single probe	2D, M, CDI	CMUT/CMOS-based	cable	Butterfly Network, USA

## Technology Behind the Butterfly iQ

The Butterfly iQ differentiates itself from all current commercially available ultrasound technology by replacing traditional piezoelectric crystal-based transducers with a single silicon chip containing a 2D array of 9000 capacitive micromachined ultrasound transducers (CMUTs). This CMUT technology used in the Butterfly iQ is based in part on research done by Stanford professor Pierre Khuri-Yakub, who now serves on the scientific advisory board for the company [7]. A single CMUT unit consists of a thin, conductive membrane separated from another conductive substrate by a vacuum gap, forming a capacitor. When a voltage is applied, the thin membrane acts like a small drum to generate ultrasound vibrations. Sound waves that are reflected back from tissues similarly vibrate the thin membrane and are recorded as an electric signal [8, 9]. Unlike piezoelectric crystals, which are tuned to oscillate at defined frequencies, CMUTs have a much wider bandwidth when they are applied to biological tissues, and therefore, a single transducer can be programmed to emit and detect many different frequencies [9]. By placing the CMUTs in a 2D array, the device can be programmed to emulate waves from any type of transducer – linear, curved, and phased (Fig. 1). As a result, a single probe can be used for whole body imaging. In addition, CMUT technology also has the advantage of being highly amenable to integration with electronic circuits, such that all of the wiring that typically connects a probe to electronic controls can

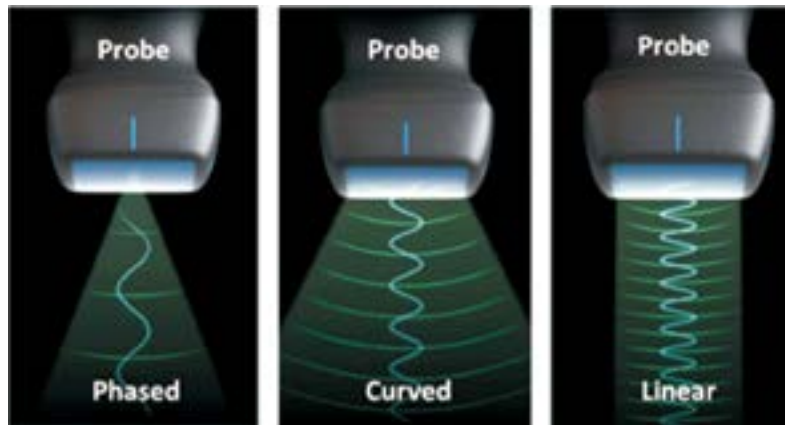
be made to fit on a single, semiconductor chip [9]. In particular, the chip for the Butterfly iQ is constructed using a widely used technology for making integrated circuits, known as the complementary metal-oxide semiconductor (CMOS) process. This CMOS-based technology, which allows for large-scale production, is also responsible for the dramatic difference in cost of the device compared to traditional probes [10].

## Imaging Features and Specifications of the Butterfly iQ

The device itself weighs 313 grams and is 144 x 53 x 26 mm in size. While the probe currently costs 2,000 USD, the device also requires a user license, which costs 420 USD per year for an individual or \$1,200 USD per year for 10 users. The user license provides access to unlimited cloud-based storage for scans to be uploaded. Currently, the Butterfly iQ is only compatible with Apple devices including iPhones and iPads (although an adaptation to Android devices is expected) and can be connected via the Lightning port or USB-C connector. It can be charged wirelessly, and once fully charged, it has a battery life of 2 continuous hours, which may be a limitation in some settings. For scanning, users can select among 19 different presets for various clinical applications, including abdomen, abdomen deep, aorta & gallbladder, bladder, cardiac, cardiac deep, FAST, lung, musculoskeletal, nerve, obstetric, pediatric cardiac, pediatric long, small organ, soft tissue, vascular:

access, vascular: carotid, and vascular: deep vein (Fig. 2). Imaging functions including M-mode, B-mode, and Color Doppler are available for each application accordingly (Figure 3 and 4). Additional settings allow

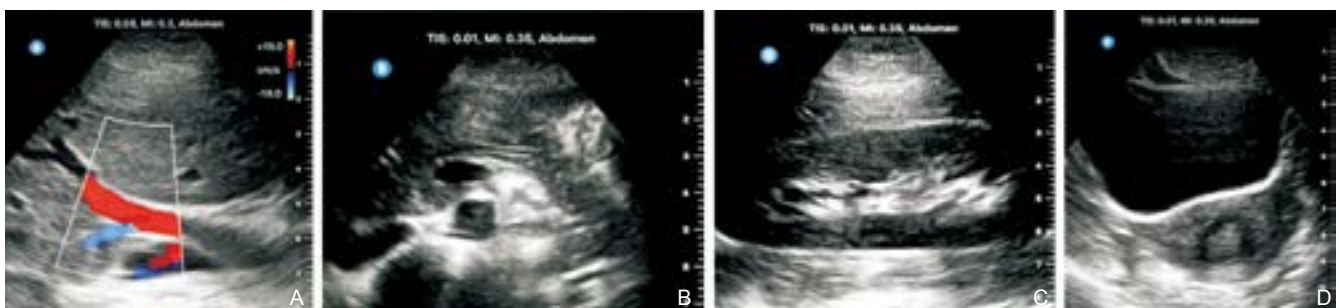
for control of gain, time gain compensation (TCG), and depth, as well as functions for measurements and annotations.



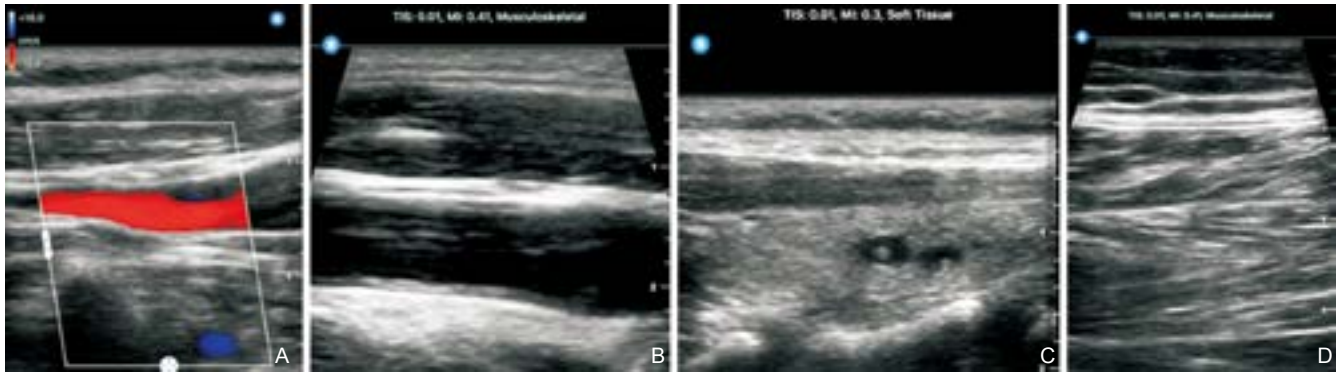
**Figure 1** CMOS-based 2D array transducer with 9000 micromachined sensors can program multiple type of probe, e.g., linear, curved or phased. (Picture was adapted from <https://www.butterflynetwork.com/iq>)



**Figure 2** (A) A handheld Butterfly iQ unit is used to scan the radial artery; (B) There are 19 preset applications available for whole body examination and a few are shown here.



**Figure 3** With selection of a specific scanning application, Butterfly iQ demonstrated abdominal imaging of the liver and the portal vein (A), the pancreas (B), the kidney (C), and bladder with uterus (D).



**Figure 4** By choosing vascular or superficial scanning application, Butterfly iQ displayed the carotid artery in color Doppler imaging (A), the thickening of the carotid wall in gray-scale imaging (B), the thyroid with colloidal cysts (C), and normal imaging of calf muscle (D).

### Future Directions and Applications

A major future potential for the Butterfly iQ is its potential interface with artificial intelligence (AI) technology. Butterfly Network has already announced that it is working towards this goal by leveraging the ultrasound scans performed and uploaded by its users to feed into a deep learning algorithm. The aim is for the software to be able to provide guidance during both image acquisition and interpretation [11]. This type of capability could expand the applications of the Butterfly iQ in several different arenas. On one hand, the company envisions that AI-guided interpretation of ultrasounds will be valuable in low resource settings that have limited access to healthcare resources, especially costly imaging modes. Butterfly has already donated scanners to charities working in low-income countries and is working with the Bill and Melinda Gates Foundation to improve software that is intended to teach untrained users as they scan [12]. On the other end of the spectrum, the accessibility of the probe, in addition to future AI technology, means that it may one day be used as a personal medical device. However, this tool is not yet FDA approved for at-home use and it is unclear if or when that would happen [7].

In summary, the Butterfly iQ has already received notable press and several honors for its breakthrough technology. Although Butterfly is the first to commercialize this new advance in ultrasound equipment, it is likely that other companies have also been working on technologies based on similar concepts. The success of Butterfly may accelerate this development and bring many more innovations to market in the next several years, leading the way for an exciting time in the field of ultrasound.

### Conflict of Interest

Authors have no conflict of interest to declare.

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