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A Q&A with the Qualcomm Tricorder XPRIZE Winners

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In recent years, there has been an increasing demand for "health consumer technologies"—small, user-friendly, point-of-care devices that can be operated by untrained individuals to evaluate health and disease. The Qualcomm Tricorder XPRIZE was a $10 million global competition to stimulate innovation and integration of advanced technologies, enabling reliable health diagnoses anywhere and anytime (https://tricorder.xprize.org/). The competition called for the development of a device that could diagnose 12 diseases (and the absence of disease) and capture 5 real-time health vital signs independent of a healthcare professional or facility. Devices also could not weigh >5 pounds and required the capability to transmit data to a cloud storage and computing system. Although diagnostic accuracy was a key component, the competition was unique in its strong emphasis on user adoption and experience. In fact, only teams scoring the highest on the consumer experience evaluations were eligible to win the overall competition.

After the competition's launch in 2012, >300 teams joined. In April 2017, 3 winners were announced. Final Frontier Medical Devices, led by Basil Harris, was announced the highest performing team and received $2.6 million for their achievement. Dynamical Biomarkers Group, led by Chung Kang Peng, received $1 million for second place. Cloud DX, led by Sonny Kohli, was also recognized as XPRIZE's first Bold Epic Innovator and received $100000.

Here we learn more about these devices and their inventors, including what inspired their teams and what hurdles they were able to overcome.

Describe your device and what it does.

Basil Harris: Our tricorder is an autonomous medical diagnostic device that leverages technological advances in wireless monitoring, artificial intelligence, and affordable point-of-care biomedical processes. Our prototype tricorder, called DxtER, comprises several innovative sensors that together form a comprehensive healthcare kit. The diagnostic engine, or the brain of the device, is an app on a phone or tablet. It encompasses our unique examination and diagnostic algorithms. The app is responsible for the fusion of data, requests for further inputs, and displays the diagnosis and suggested courses of action. The app provides the user guidance on how and when to call on the kit's peripheral devices, which include a noninvasive blood glucose monitor, a quick urine test, and a blood pressure cuff, among other technologies. Our solution not only achieves the goal of diagnosing diseases and continuously monitoring vital signs, but it is also able to perform these tasks in revolutionary new ways that are noninvasive. We have developed, and continue to advance, methods for measurement of blood glucose, hemoglobin, and white cell counts that do not require needles or other implantable devices.

Chung Kang Peng: Our system implemented an artificial intelligence algorithm to interact with the user to identify potential diseases from a group of 12 possible

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medical conditions. In addition to continuous 24-h monitoring of vital signs, our system guides the user to carry out necessary diagnostic tests. This may include blood, urine, imaging, and physiological signal analyses. We developed our own image and signal analysis tools for accurate disease diagnosis.

Sonny Kohli: Our tricorder is called Vitaliti and consists of a smartphone hub that pairs/communicates with 3 peripheral components in the spirit of the original tricorder: (*a*) a neck wearable that functions as a continuous vital sign monitor, (*b*) a desktop laboratory (in vitro desk station) that allows for biomarker collection and quantification, in addition to component storage and battery charging, and (c) the spirotoscope—a combination hand-held/wireless spirotometer and otoscope. Artificial intelligence-based computational techniques are then used to compile and process patient interview questions with tricorder-derived vital signs and physiological information to arrive at medical diagnoses. Easy to understand advice is then provided to aid users in managing their newly diagnosed condition. This information is delivered by a prerecorded video message from me, just as I would with my patients in a face-to-face encounter.

What inspired you to enter the Tricorder XPRIZE competition?

Chung Kang Peng: We recognized a need for a device that was low cost with a low technical barrier for operators to aid medical care in remote locations. Our goal was to develop technologies for mobile clinics that could be deployed in rural areas of the developing world where it was unlikely to have sufficient numbers of qualified medical professionals to perform the necessary diagnostic evaluations.

Sonny Kohli: I was volunteering in Haiti after the earthquake in 2010, and encountered several patients for whom I did not have the investigative equipment that I typically needed for diagnosis. I then realized that portable autonomous equipment that would leverage the near ubiquitous nature of a smartphone and cellular access to the Internet could profoundly improve global access to medical care. So, I started in earnest with a small team building a mobile phone-based 12-lead electrocardiogram. In 2013, I was cold-called by Robert Kaul, who introduced me to the Tricorder competition. We decided to build an entirely new small team to create an entry in this competition. With no money and few resources, we trudged along and made it to the finals! It was at that point that we decided to create a company around our new tricorder, called Cloud Dx.

Basil Harris: As an emergency physician, I witnessed daily how the US healthcare system was failing so many patients. My team and I believed that we were successfully developing a diagnostic device that would dramatically improve healthcare delivery. With our healthcare kit, consumers would be empowered with significant information about their health, as well as answers to pressing medical questions when they needed them. It is important to note, however, that we do not see tricorders as replacing medical providers, but rather as a tool to make our jobs more efficient. Patients would have improved communication with their doctors and, ultimately, better health outcomes. Medical professionals would see patients better engaged in their own health. Healthcare providers could access real-time, medically accurate monitoring data to more effectively aid patients in maintaining wellness, and likewise provide expedient complex diagnostics and care management.

What was the biggest technical challenge you faced related to measurement of biomarkers?

Sonny Kohli: Biomarkers derived from nontraditional sources like saliva are a challenge to acquire autonomously. Ultimately, overcoming user/consumer inertia in acquiring their own biosamples was our biggest challenge and victory. We did so by creating a unique collection experience. Together with our team in Canada, our partners at Dr. Shan Wang's laboratory at Stanford helped create a novel, painless, and easy-to-use platform for collection of saliva and other bodily fluids. We engineered a novel tool for blood collection by finger prick, using a pressure-triggered small-caliber cannula that acquired the sample with a mechanism that "hid" the needle before and after collection. This device could then be inserted into our desktop in vitro diagnostic unit for automatic interpretation. For saliva collection, we engineered a tool that could both collect salivary secretions on a cotton swab and coalesce them into a concentrate for subsequent quantification in the in vitro diagnostic unit. Urine collection deployed a similarly engineered tool to simplify the process. To facilitate the collection process, we coached the user with step-by-step graphics and instructions on our mobile app. Stabilizing our reaction reagent on the test surface of our collection apparatus was

also a challenge (as it was prone to degradation because of moisture and temperature changes). Lastly, the epoxy we used to glue together our collection cartridges ended up interfering with our measurement technique. This was unanticipated and a difficult problem to both diagnose and solve.

Basil Harris: Some of the simplest of tasks can often turn out to be the most challenging. Developing the artificial intelligence for automating the medical diagnostic process was certainly a bigger undertaking than we imagined. Also, not trivial, was creating routines, algorithms, and machine-learning exercises to teach the system how to interpret data streams from running vital signs, continuous electrocardiogram rhythm leads, and lung sounds from auscultation. However, the biggest challenge was entrusting the end user with the tasks necessary to capture reliable data—whether it be correctly applying sensors on the skin or testing a blood, urine, or saliva sample. Our urine test card, for example, uses the smartphone or tablet camera and must be able to run in a variety of settings. Ensuring that a nonexperienced user can capture reliable data is critical. Making a task simple for the end user does not engender a compromise on quality. It only increases the burden on the developer.

As clinicians, we need to appreciate that this type of technology is coming whether we are involved or remain on the sidelines. We need clinicians and laboratorians to guide its development and direct the conversation. We understand the importance of obtaining real and reliable data. We need to demand that devices coming to market, like these tricorders, deliver worthy medically significant data. The more robust the technology is, the more likely it will be adopted into practice. We stress the importance of obtaining accurate and medically significant data that are reliable enough to be used to make actionable medical decisions. Our strategy is to work within the medical community and conduct rigorous clinical trials to bring this technology to life. Although it is tempting to release new technology to an eager audience, we believe that premature deployment would be detrimental to the overall goal and have chosen the tougher path toward validation through trials and evidence collection. In the end, the more robust the technology is, the more likely it will be seamlessly adopted into practice. We believe that this balanced approach will build trust in our new technology.

Chung Kang Peng: Because the entire system had a weight limitation of 5 pounds, it was challenging to apply innovative technologies for blood testing. As a result, we had to use more conventional technologies for biomarker detection (i.e., using test strips that require the right amount of blood and proper dilution with chemical solution). This involved tasks that proved challenging for regular consumers and led to less accurate results.

During this process, did you reach a point where you almost gave up? If yes, what was it?

Chung Kang Peng: No, our team has been lucky that we carried out the development of our system smoothly. Although some of our original plans did not work, we were fortunate that our back-up plans worked.

Sonny Kohli: There were many times when we either ran out of money or faced some other catastrophic issue that forced us to ponder quitting. Not getting approval from Health Canada to test on patients until the final hour was one of those more memorable moments.

Basil Harris: We reached many points during the competition when we expected to be eliminated. We entered the Qualcomm Tricorder XPRIZE competition as 1 of 312 teams from 38 countries, and we knew from the start that the odds were stacked against us. Despite these odds, we had no intention of giving up. The timeline of the Qualcomm Tricorder XPRIZE was by design a huge challenge. In part, it was how they accelerated the development of technologies behind each XPRIZE.

The Tricorder XPRIZE competition has many restrictions, such as size and weight and monitoring 5 vital signs and assessing various conditions. If you could have changed 1 criterion, what would it have been and why?

Chung Kang Peng: I would have relaxed the weight restriction, maybe to 10 pounds, instead of 5. This would have given us more freedom to develop more innovative technologies that are bulky and heavier in the initial stage of development, but which would certainly become more compact and lighter as time goes by.

Basil Harris: We would have loved to incorporate some third-party devices into our system. The competition restricted us to our own equipment. Although this did allow us to create some novel devices, moving forward we will provide an open platform in which data from any trusted source can be included. The ultimate tricorder would be an amalgamation of the best components of all the finalist systems.

Sonny Kohli: I would not have changed any criteria. Rather, I would have enforced 1 of the criteria. The blood pressure requirement was supposed to be noninvasive and continuous (i.e., streaming). This would have been a true leap forward in the current state of the art. Instead, most teams used legacy technology and periodic blood pressure measurement via an arm cuff. This was not in the spirit of the competition but did serve the intended purpose. We created a continuous, noninvasive blood pressure monitor.

Where do you see the technology you invented being used in the future?

Sonny Kohli: I see many potential uses: (*a*) at home for high-risk patients requiring continuous monitoring, (*b*) postoperative high-risk patients being discharged home early or being set up in a virtual hospital ward at home for ongoing care, (*c*) athlete training and monitoring of performance, (*d*) advanced health and wellness metrics (like a Fitbit® on steroids), and (*e*) in remote places where access to high-fidelity monitoring like that needed in an intensive care unit or an operating room is challenging and/or unavailable.

Chung Kang Peng: We are pursuing our goal to develop our second-generation system that can be used in rural areas where no healthcare resources are available. To accomplish this, we are working with collaborators in medical institutions and government agencies in China.

Basil Harris: More than 1 billion people across the globe lack access to comprehensive and affordable high-quality healthcare services. In many ways, the need for access to services is as critical in Syrian refugee camps as it is in the urban center of Philadelphia. The ability of an individual to diagnose what disease he or she has (or does not have) is empowering to that individual, their family, and their community.

A device providing meaningful, reliable health information and diagnoses is new to a market of 1-dimensional wearables. Tricorders will inspire people to be more engaged with their health and will improve their well-being and productivity, causing a positive ripple effect with far-reaching benefits.

Deployed at scale, this technology will lessen the 2 major systemic barriers to accessing healthcare: cost and provider shortages. First, our health kit could act as a triage system, giving people answers when they need them, guiding them to appropriate action and care, and helping them monitor and manage their health outside of a provider's office. Our health kit could reduce existing inefficiencies in the healthcare system, helping to lower costs. Second, this technology is adaptable and could be deployed anywhere in the world, bringing diagnostic capabilities to remote villages and underserved communities. The health kit would be a catalyst to help people access the answers they need in real time, regardless of logistical constraints. Barriers to providers working with patients would virtually disappear, as more providers could remotely monitor and communicate with their patients.

These devices are designed for healthcare consumers to use. What do you see as the future role of individuals in their own healthcare?

Basil Harris: Tricorder technology, or automated/technology-assisted diagnosis, is in its infancy, and as it matures it will provide basic medical triage and basic medical diagnosis in support of medical personnel, especially in areas where the number of medical professionals cannot support the population. This is true in many developing areas around the world, as well as in highly developed areas where access to healthcare remains a huge barrier.

Tricorders will not replace human doctors but will assist them. The fact that the tricorder's underlying diagnostic engine can explore more possibilities, never tires at looking at data, and provides a consistent view of data will make it a valuable tool in a medical professional's arsenal. Having sensor devices like this at home will allow users to collect data, monitor their health, and advise when to take action, in partnership with their doctor and/or the local urgent care center or emergency room in cases when further action is deemed appropriate.

Chung Kang Peng: Ideally, in the future, most diagnosis and medical care will be performed at the patient's home. Therefore, the sensors to gather accurate information from the patient must be user-friendly. Collected information will be uploaded to the cloud, where artificial intelligence-based expert systems will provide meaningful interpretation to the patient.

Sonny Kohli: Self-management, remote management, and patients being more vested in their own health will be the inevitable reality of a strained healthcare system with insufficient resources to care for The Silver Tsunami. Therefore, tools that facilitate self-care and remote management will be vital.

What type of a device do you think the Tricorder XPRIZE of 2025 would be asking for?

Chung Kang Peng: I hope a true "tricorder" system, which is a hand-held scanner that can scan the patient completely noninvasively to make the diagnosis.

Sonny Kohli: Completely noninvasive biomarker collection and quantification, entirely artificial intelligence powered, with a "zero interface," meaning patients do not even know that it is present while their health is being monitored.

Basil Harris: The XPRIZE of 2025 would be asking for completely noninvasive tricorders that can reliably diagnose and advise the user without any blood samples.

Moderators: We want to thank the experts for their careful and thoughtful replies to our questions. The Qualcomm Tricorder XPRIZE incentivized technologic breakthroughs needed to enable a digital health revolution. This involved leveraging the ubiquity and ease of use of mobile consumer devices with innovations in sensing and artificial intelligence to create potential for im-

proving the affordability, access, and effectiveness of care for more people. The radical advancements achieved by these teams, often on relatively limited budgets, are not limited to technology. Inherent to the process and the devices are disruptions and impending evolution in product development and regulatory pathways, healthcare delivery and business models, and infrastructure. Whether through these devices or others that follow, the Tricorder XPRIZE forged a path to bring science fiction significantly closer to reality.

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