Standard Review Article

Sensors and digital medicine in orthopaedic surgery

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Abstract

Digital health principles are starting to be evident in medicine. Orthopaedic trauma surgery is also being impacted —indirectly by all other improvements in the health ecosystem but also in particular efforts aimed at trauma surgery. Data acquisition is changing how evidence is gathered and utilized. Sensors are the pen and paper of the next wave of data acquisition. Sensors are gathering wide arrays of information to facilitate digital health relevance and adoption. Early adaption of sensor technology by the nonlegacy health environment is what has made sensor driven data acquisition so palatable to the normal health care system. As it applies to orthopaedic trauma, current sensor driven diagnostics and surveillance are nowhere near as developed as in the larger medical community. Digital health is being explored for health care records, data acquisition in diagnostics and rehabilitation, wellness to health care translation, intraoperative monitoring, surgical technique improvement, as well as some early-stage projects in long-term monitoring with implantable devices. The internet of things is the next digital wave that will undoubtedly affect medicine and orthopaedics. Internet of things (IoT) devices are now being used to enable remote health monitoring and emergency notification systems. This article reviews current and future concepts in digital health that will impact trauma care.

Keywords: digital health, internet of things, monitoring, sensors, wellness

1. Introduction

Medicine is undergoing yet another evolution. Data acquisition is changing how evidence is gathered and utilized. Sensors are the pen and paper of the next wave of data acquisition. Sensors are gathering wide arrays of information to facilitate digital health relevance and adoption. Slow progress for penetration of the orthopaedic trauma world has been evident. Digital health is influencing care and orthopaedic surgeons will eventually take advantage of this innovation. Digital health is a loosely defined term that refers to the use of information technology and electronic communication tools to deliver care services or to facilitate better health. It has come to mean integrated, interoperable, and digitally enabled care environments that manage health and wellness to transform care delivery. The impact of the wellness industry to drive health care is not to be trivialized. Early adaption of sensor technology by the non-legacy health environment is what has made sensor driven data acquisition so palatable to the normal health care system. The data volume and usefulness are what makes digital health so interesting. As it applies to orthopaedic trauma, current sensor driven diagnostics, and surveillance are nowhere near as developed as in the larger medical community.

Sensor technology in orthopaedics is on the rise but practical application has lagged other medical specialties.[1,2] Digital health is being explored for health care records, data acquisition in diagnostics and rehabilitation, wellness to health care translation, intraoperative monitoring, surgical technique improvement, as well as some early-stage projects in long-term monitoring with implantable devices. The internet of things (IoT) is the next digital wave that will undoubtedly affect medicine and orthopaedics. IoT is made up of intercommunicating physical objects that are usually embedded with sensors and actuators. They have processing ability, embedded software, and other technologies that connect and exchange data with other devices and systems. So, the so-called dumb objects that make up our environment have been imbued with the ability to interact with each other and their surroundings. This can be over the Internet or with other communications networks. IoT devices are being used to enable remote health monitoring and

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EJH is a founder of NXTSens Inc, MY01 Inc, and Stathera Inc—all of which are sensor companies. Sensor companies and MY01 are discussed in this manuscript.

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emergency notification systems.[1,3–5] These health monitoring devices can range from blood pressure and heart rate monitors to advanced devices capable of monitoring specialized implants,[4] pacemakers[6] and Fitbit electronic wristbands.[7,8] Some hospitals have begun implementing intelligent beds[9] that can detect when they are occupied and when a patient is attempting to get up. These beds can also adjust themselves to ensure appropriate pressure and support is applied to the patient without the manual interaction of nurses.[9] There are a few key areas of healthcare loT that could bring in revenue: remote patient monitoring (which includes chronic disease management), telehealth, and behavioral modification. These are all easily attainable goals for loT early wave devices.

2. Health care records

Orthopaedic surgeons currently see some immediate benefit from digital health. Artificial intelligent systems aside we see new and improved methods of delivering health care information that helps with normal health care. Future directions include interactive infographics and the ability to do a deep dive on patient data.[10] Real time analysis of patient information and demographic parameters will allow more meaningful interactions and in depth views of what is happening in patient care.[11] This represents a natural progression of health records.

3. Data acquisition in diagnostics and rehabilitation

Mobile outpatient monitoring is one segment of loT Healthcare. The use of mobile devices to support medical follow-up is referred to as m-health and is a sensor laden approach to useful health statistics.[12] Advances in electronics fabrication methods have enabled ultra-low cost, use-and-throw loMT sensors. These are reliably manufactured in bulk processes.[2] These sensors, combined with new low energy communication technology and expanded internet protocols have made for exciting potential in health care surveillance. Certainly, everyone has seen the advertisements for glucose sensors that ensure appropriate insulin supply.[2,13] Sensors can be fabricated on paper or etextiles for wireless powered disposable sensing devices.[14,15] Devices have recently been brought to market for niche problems in diagnostics. One example is the MY01 device (Fig. 1), a MEMS sensor product designed to aid in the diagnosis of acute compartment syndrome.[16] This device represents a true transition to digital health as it has an accompanying application for real time data retrieval designed to not only allow cloud based remote viewing but integration with electronic health records. Some next generation commercially available glucometers, like the Dexcom G6, are now equipped with real time data retrieval (Fig. 2).

4. Telehealth and the wellness to health care translation

Health care by Zoom and other telemedicine tools is already here [17,18] facilitated by the needs of the Covid pandemic. Surgical care by telehealth [19–22] is the next step here and has been explored by many people interested in long distance care or for oversight of patient safety during remote procedures.[23,24] We are currently seeing an adoption of wellness sensors to monitoring health.[25–30] There is usage of wearable device integrations that can monitor patient's vital signs such as heart rate and blood pressure.[31] Patients are more than willing to accept new technology and the gamification of rehabilitation.[3,4,32] The increasing use of telehealth could reduce the cost of doctor's visits by as much as 75%, and about half of all doctor's visits could be conducted online. Specialized sensors can be patient centric or placed within living spaces to monitor the health and general well being of patients.[33] These sensors create a network of intelligent sensors[12,34] that can collect, process, transfer, and analyze valuable information in different environments.[35] However, some reviews have been unable to find an improvement on in person clinic visits.[36] The goal is to connect in-home monitors and sensor arrays to hospital-based systems.[1,6,32,35,37,38] Its applications to orthopaedic surgery are multifold- patient rehabilitation monitoring,[39] medication compliance, and wellness utilities are now available or soon will be possible.[32,35]

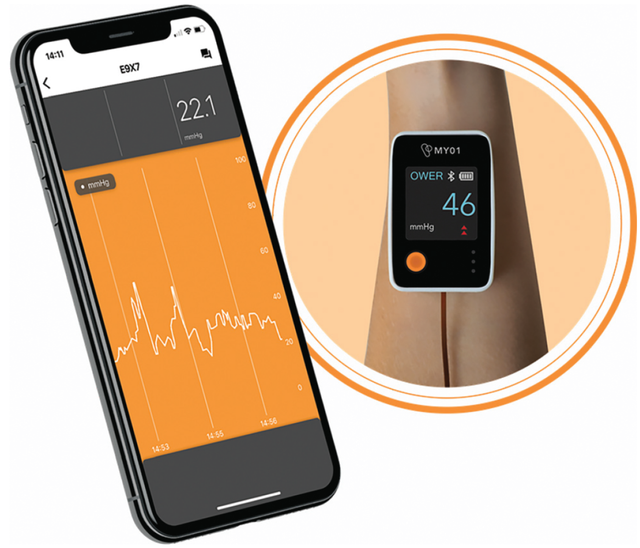

Figure 1. MY01 compartment syndrome sensor—designed to allow real-time cloud-based data retrieval and display in a smartphone application, the electronic health record, and at the bedside.

5. Surgical technique improvement

Last to the table is innovation in intraoperative sensors for orthopaedics. We see the typical me-too usages for robotics but have yet to see a real breakthrough in which the robot performs the surgery. Certainly, orthopaedic surgeons utilize robotic technology to improve outcomes in the operating room- but these devices are more of a check rein to surgical technique. There are new options for aid in reduction of fractures, but they are not in widespread usage.[40–43] Several products are being investigated for in surgery usage but are really limited to total joint surgery[44–46] and have not been applied to trauma surgery. One of these products is Verasense —marketed as a disposable device that delivers data wirelessly to an intraoperative monitor that enables decisions regarding implant position and soft-tissue releases (Fig. 3).

6. Long-term monitoring with implantable devices

The application of IoT in orthopaedic surgery can play a particular fundamental role in managing chronic diseases and in disease prevention and control which for orthopaedics can be fall

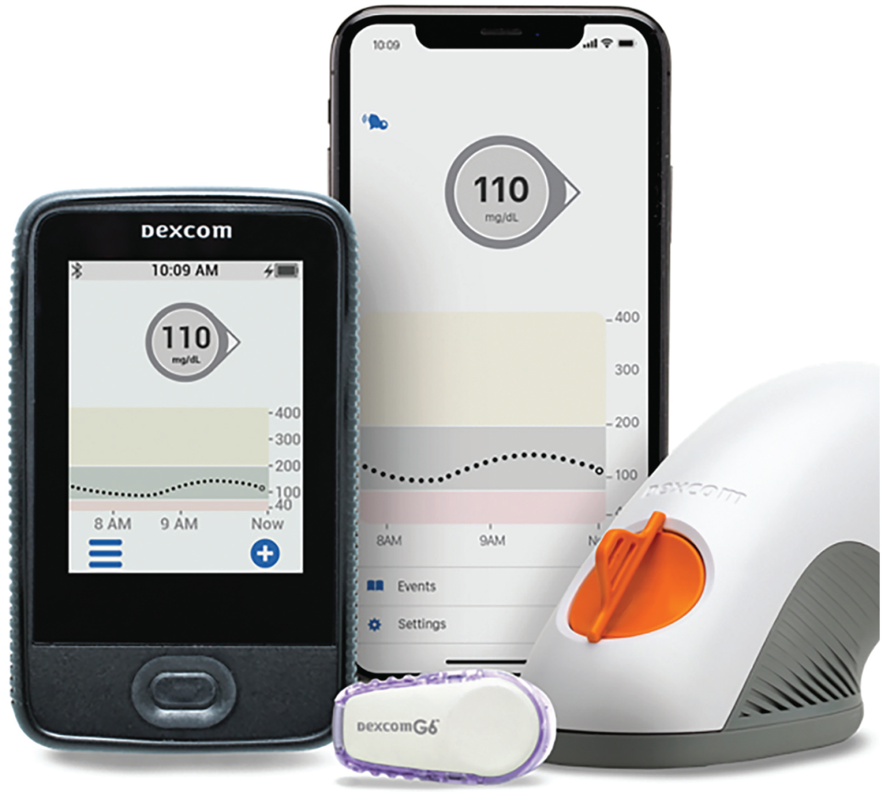

Figure 2. Dexcom glucose sensorsystem—designed to have realtime read out to a patient-oriented application. From public access site —https://www.dexcom.com/en-CA/en-ca-dexcom-g6-cgm-system.

and accident prevention amongst other applications.[33,47–51] One of the main issues for IoT (besides ethical concerns) is the actual amount of data that will be generated. IoT data is measured in zettabytes, a unit equal to 1 trillion gigabytes. There are estimates that the IoT generates more than 500 zettabytes per year in data—and in the years to come, that number is expected

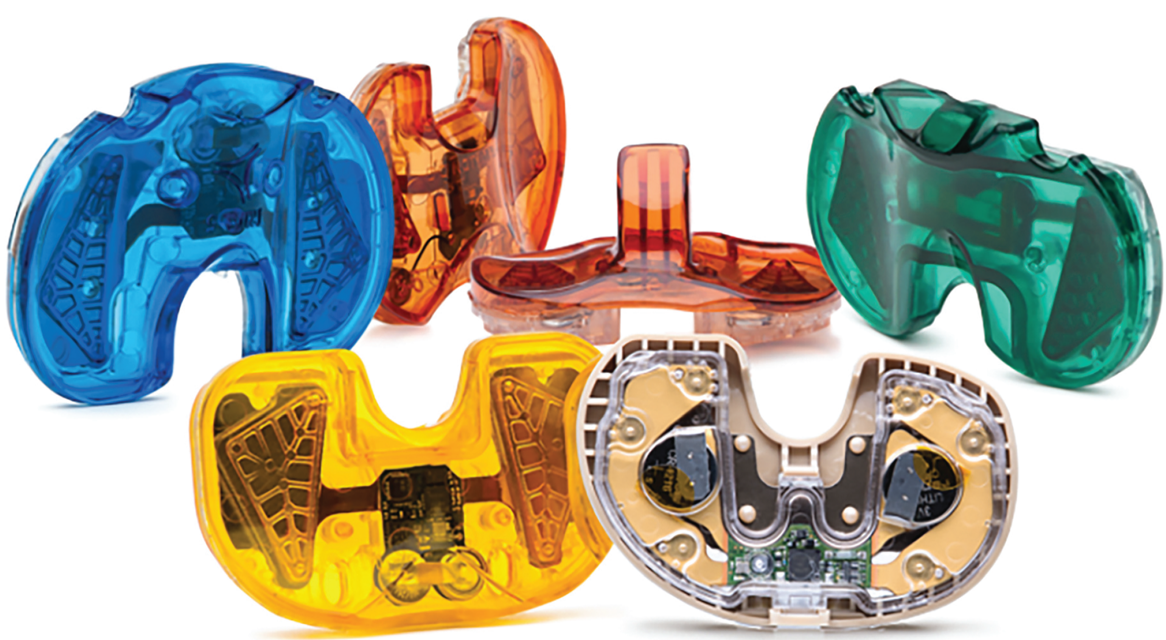

Figure 3. Verasense Total Knee tray—designed to allow intraoperative sensing at the level of the tibial tray. The tray is discarded at the end of the case and a polyethylene tray is placed in the normal position. From public access site—https://www.orthosensor.com/surgeons/verasense/.

to grow exponentially, not linearly. As the science and practice of virtual care continues to evolve, sensor solutions capable of monitoring many parameters (e.g., oxygen saturation, heart rate) continuously and simultaneously will be brought on board.[4] Through seamless integration of multiple signals, these technologies can generate high-volume big data for the development of algorithms to facilitate early detection of changes in patient health status and timely clinician response. Currently few options exist. Usage of sensors for infection are coming to market.[52] Most common is the use of sensors for intraoperative measurements in total joint arthroplasty.[52–55] Very few indwelling options are available.[49,56] One device has been designed for allowing pressure monitoring in total knee arthroplasty to determine imbalances of force.[57] A platform that may hold promise was reported by Cai et al,[49] in Nature Communications. They discussed a device that uses integration with the surface of the bone to allow chronic monitoring in small and large animal models. This potentially will be transferrable to more human settings.

What do we get from digital health? We get better medical records right now. We get telehealth and wellness monitoring. We get a lot of data from external sensor arrays and software packages in current design process. We also can merge wellness and healthcare for meaningful data.

But in the end, we need a lot of information from internal sensors to change orthopaedic health care. Wireless battery-free devices attached to bone during orthopaedic surgeries can potentially form a chronic interface with bone tissues to directly record physiological and biophysical signals critical for the assessment of musculoskeletal health. This may be able to provide a point-of-care platform and the necessary data to facilitate rehabilitation and manage musculoskeletal diseases. This is the future, but it looks attainable. More projects like this will only facilitate the utility of sensors in orthopaedic surgery.

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