

# THE FUTURE OF PATIENT MONITORING: HOW DIGITISATION AND USER EXPERIENCE ARE IMPACTING PRODUCT ROADMAPS

JUNE 2019



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# 1 EXECUTIVE SUMMARY

Patient monitoring is an inherent part of patient management. Intermittent and continuous measurements are used to define disease states, characterise disease progression and monitor recovery. They are used to help set therapeutic approaches, to assess whether an intervention is having the desired effect and to check that the patient is always safe.

The monitoring of patients within a clinical setting is changing; new market entrants, new business models and the IoT revolution are providing more insight into the patient condition through novel data feeds and analytics. The drivers for change are numerous, such as the containment of cost, improvement of patient care and better clinical outcomes. The shift from treating illness to managing health is also demonstrated by an increase in the use of monitoring outside of the clinical setting, in addition to a change in the breadth of what is monitored.

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*“The monitoring of patients is changing; new market entrants, new business models and the IoT revolution are providing more insight into the patient condition through novel data feeds and analytics.”*

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This includes both physiological measurements (such as blood pressure, heart rate and stress) and behavioural measurements (such as medication adherence and compliance). These changes require us to re-think our traditional approach to the development of patient monitoring technology and to ensure we harness the technical enablers safely and effectively to develop products that improve on current monitoring methods, both within and outside of the hospital setting.

In this whitepaper we explore some of the key drivers affecting how patients are being monitored and the role that technology is playing in supporting and driving these changes. We also explore what this means for strategic marketers and R&D teams at device companies active in this space, and how they need to adapt their product and technology roadmaps to make sure they remain competitive in the next 10 to 15 years.



## 2 INTRODUCTION

There is tremendous pressure on healthcare systems to provide holistic, efficient and personalised healthcare plans, improving outcomes whilst containing costs in the face of growing demand. With the shift to value-based healthcare, payers are increasingly unwilling to reimburse care costs arising from adverse events and avoidable care complications.<sup>1</sup> This places a strong economic incentive on healthcare providers (HCPs) to implement procedures and protocols that minimise the incidence of complications along the entire length of the patient pathway, through data collection and predictive analytics.

This is epitomised in the case of enhanced recovery programs for surgery, where a care package is designed to cover the entire patient journey. Firstly, patients are screened for conditions associated with increased risk of complications and poor outcomes. This data supports prehabilitation recommendations to optimise functional capacity, such as smoking cessation, anaemia treatment and control of glucose levels. Next the intraoperative care bundle aims to minimise inflammatory response, manage pain with a minimum of opioid use and to allow early mobilisation of the patient. Lastly, arrangements are put in place to discharge the patient as soon as possible, to recover and rehabilitate in the home environment, which is associated with improved satisfaction and outcomes.

### 2.1 REMOTE MONITORING AND HOME HEALTHCARE

Remote patient monitoring (RPM) has seen exponential growth in recent years,<sup>2</sup> boosted further by the widespread adoption of consumer wellbeing monitoring and, more recently, its subsequent convergence with long-term healthcare monitoring in the home and other non-clinical environments.

Initially aimed at exercise monitoring, wellness devices, including fitness tracking, sleep optimisation, stress management and home monitoring of elderly and other vulnerable population groups, have grown in scope to support users in broader lifestyle improvements. RPM in these environments can be as simple as a watch that can detect a seizure and send a signal to a centralised patient care facility, or a necklace with a button that activates a call for help following a fall by the user. Similarly, dementia patients can be helped by wearing a GPS watch tracking their location, in cases where they become lost or disoriented.

More sophisticated systems are also proving to be effective healthcare support tools by using data aggregation from a variety of health and wellbeing devices, combined with analysis and artificial intelligence. Tactio, a Canadian digital health provider, offers a configurable smartphone app-based data management platform, that aims to shift care from the hospital to the home. The platform helps in managing patients' healthcare goals, such as weight loss, diabetes management or cholesterol reduction, by tracking and analysing factors such as weight, blood pressure, activity, diet and blood glucose levels. The data can be entered manually or via a variety of connected medical and wellbeing devices, including medical and consumer-grade wearables. Not only a data aggregator, it sends messages to the patient throughout the day to manage key health factors and nudge behaviour at home, such as prompts to take exercise or maintain a healthier diet. All of this can be monitored and subsequently tailored by the physician.

Traditional medical device players, such as Abbott, Philips Healthcare and Medtronic, are entering the home healthcare market, leveraging the widespread usage of smartphones with their existing presence and expertise. Abbott has already launched an implantable cardiac monitor that syncs with the patient's smartphone via an app, and which continuously monitors for syncope, palpitations, and atrial fibrillation. Scheduled transmissions ensure continuous patient care while minimising clinical staff burden. By utilising an implant, their platform is firmly within the realm of medical devices, yet the platform works by means of pairing it with an app that focuses on user experience, ease of use and accessibility. We believe that the quality of user experience seen in consumer products and services will set the bar and become the expected standard in the medical device space.

We expect to see the increasing use of behavioural and physiological monitoring using variables such as mental health symptoms and medication adherence, driven in part by the pharmaceutical industry. Medication non-adherence costs the global pharmaceutical industry \$637 billion per annum<sup>3</sup> in lost revenue. This is driving the adoption of home monitoring to nudge behaviour toward compliance, through a combination of sensing, analytics and great digital design.

A well-known early example in this space comes from Propeller Health, whose app and connected inhaler sensor allows patients to track their medication use, as well as to input and monitor their symptoms and any impact on their day-to-day activity, through subjective self reporting.

Remote monitoring can also be used as a treatment, under the right circumstances and conditions. A 2011 study by Chausiaux et al. demonstrated that infertile couples seeking In-Vitro Fertilisation (IVF) treatment could attain the same pregnancy rate using Duofertility, a combination service, wearable, and app, over a six-month remote monitoring program, at 5% of the cost of IVF.<sup>4</sup>

## 2.2 NON-TRADITIONAL PLAYERS ARE ENTERING THE MARKET

With changes in the reimbursement environment and mounting evidence pointing to the as-yet untapped potential of telehealth in many countries, non-traditional medical device manufacturers are increasingly eager to enter and disrupt the healthcare market.<sup>5</sup> Technology companies that more traditionally operated in the consumer space, such as Apple, Google, Microsoft and Amazon, understand the value of structured data and AI, coupled to a well-designed user experience when driving consumer engagement. All of the 'Big 4' tech companies in healthcare have amassed huge amounts of consumer data, have generated significant insight from that data and have patented many sensing technologies that aim to disrupt the current monitoring market<sup>6</sup>. Furthermore, they are highly skilled at offering useful digital services alongside beautifully designed wearables and electronic products. Out-of-hospital care therefore seems set to become a viable and increasingly competitive route for new players to enter the healthcare industry, although there will be significant privacy and data ownership hurdles to doing this in the medical space.

Unlike hospital-based monitoring, being able to provide a direct-to-user healthcare offering that can work outside the clinic, will shift demand and therefore directly compete with the offerings of traditional medical device players, introducing disruptive business models in doing so.

We are seeing these approaches starting to be applied back into the hospital setting, for example with Philips experimenting with monitoring as a service offering.<sup>7</sup> The Arcadia Choice brand,<sup>8</sup> sold exclusively by Amazon, includes blood pressure monitors, cuffs and glucose monitors that can all wirelessly connect to an app, providing the user with graphs and the ability to share their readings with HCPs.

## 2.3 BUSINESS MODELS ARE EVOLVING

Insurance providers and healthcare services alike have an incentive to prevent people from becoming hospitalised in the first place, a dynamic which is blurring the boundaries between healthcare and wellbeing. This is reflected by payers in the US transitioning from a fee-for-service to value-based healthcare models when the 2010 Affordable Healthcare Act (ACA) was passed and more recently in the UK, by the National Health Service (NHS) and Public Health England, who have described plans to focus more on preventative care.<sup>9</sup>

The reimbursement landscape will continue to push towards care outside of the hospital setting. In May 2008, the UK Department of Health's Whole System Demonstrator (WSD) launched, involving 6,191 patients and 238 GP practices in a twelve-month telehealth trial. The trial used a cohort of patients suffering from chronic obstructive pulmonary disease (COPD), heart failure or diabetes, and demonstrated a 45% reduction in mortality rates, a 20% reduction in emergency admissions and an 8% reduction in tariff costs.<sup>10</sup>

More recently, the US has also acknowledged the future shift in healthcare, significantly amending reimbursement codes to cover remote care via video conferencing and other technologies, whilst also removing restrictions around service sites being required to be medical sites. As CMS (Centres for Medicare and Medicaid Services) is the most significant single payer in the US market, and lack of reimbursement was cited as the single biggest obstacle to widespread adoption of telehealth, this shift will significantly broaden the reach of home healthcare.<sup>11</sup>

These financial drivers, coupled with increasing technology capabilities, such as wearable medical technology, will continue to impact the overall structure of hospital-based care and lead to care increasingly being carried out in non-clinical environments and monitoring a wider range of parameters.

As the monitoring device itself becomes a smaller part of an overall service offering, manufacturers will need to identify where they want to position themselves in the value chain to avoid becoming commoditised. The increased technical, clinical and organisational capabilities required in this changing market will require device companies to build out their current ecosystems to include the digital elements that can engage, retain and provide value for patients and healthcare providers alike. This digital transformation will necessitate forming strategic partnerships with different and non-traditional supply-chain partners in order to remain competitive.

## 3 HOW DESIGN AND TECHNOLOGY WILL IMPACT PATIENT MONITORING

The world is becoming increasingly digitised, with highly compelling and convenient consumer products and services that were unimaginable at the turn of the millennium, such as streaming services, modern smartphones and VR gaming headsets. The technologies and techniques that have enabled these consumer products will increasingly be applied to patient monitoring and will transform the market.

Patient monitoring will play a major role in the growth of digital health, where data is collected, analysed for insights and presented back to key stakeholders and seamlessly transferred to records. Systems will not just report numbers but will increasingly support the user in making suitable and timely clinical decisions. While usability, from the perspective of risk identification and reduction, is core to modern medical device development, consumer devices set an expectation of excellent user experience design.

With a wider remit for monitoring, new technologies will emerge to address the growth in behavioural and physiological sensing. The demand for monitoring outside high-acuity settings will drive the development of devices that have lower impact on the patient and are more compatible with and acceptable for everyday use.

These aspects are explored in more detail below, together with the technologies that will help to address these unmet needs.

### 3.1 USER-CENTRED DESIGN

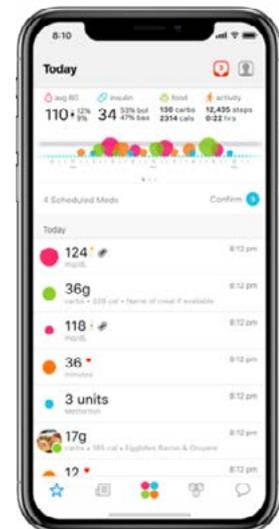
#### 3.1.1 DESIGNING FOR NEW ENVIRONMENTS AND USERS

The move towards remote and less invasive patient monitoring has the potential to provide significant usability benefits to both patients and HCPs. However, successful monitoring technology that works outside of the carefully controlled hospital setting must be designed with user and environmental factors in mind. Poor user-centred design of wearables and home monitoring systems may inadvertently introduce new usability difficulties, resulting in poor, intermittent or no data being acquired for effective clinical decision support (CDS).

Patients and lay caregivers are increasingly becoming the intended end users of the newly designed RPM technology. Consequently, when factoring in the requirement for a robust, reliable and user-friendly RPM system, we will need to consider more varied end-user demographics, such as vision, dexterity,

#### SUCCESSFUL DIGITAL ECOSYSTEMS WILL PROVIDE THE RIGHT INFORMATION TO THE RIGHT USER IN AN UNDERSTANDABLE FORM

One Drop is a diabetes management platform that combines Bluetooth glucose meters, strips and lancets with online coaching programs from certified diabetes educators. A mobile app tracks and analyses blood sugar, medications, food and activity. Users can share reports with their healthcare provider and loved ones and keep on track with progress via the award-winning interface and personalised insights.



ability to learn new information, and levels of technology literacy, and more varied environmental conditions such as lighting, temperature, humidity levels and distractions.

Additionally, the increased connectivity and processing capabilities offered by 5G technology, together with advanced analytics, will be able to provide a higher quantity and complexity of information to the end-user. Presentation of a wider range of information to HCPs, patients and/or caregivers gives the opportunity to provide more insight, but unfamiliarity could also increase the likelihood of the user misreading or misinterpreting information. The design of the data output for the end user should be carefully considered based on their needs and capabilities, including avoiding an increase to the clinical workload for the time-limited HCP, users' cognitive load in an already stressful environment, or causing unnecessary worry and concern for lay users.

Harnessing the power of artificial intelligence (AI) and machine learning to develop data interpretation algorithms could reduce the complexity of the data presented and ultimately reduce the burden on HCPs and other end users. We can also develop multiple outputs and viewing platforms, tailored to the specific end user and their needs, and designed to provide them with only the information that they require.

### 3.1.2 DESIGNING FOR SOCIAL ACCEPTABILITY

Another consideration when designing the user experience for RPM relates to the social acceptability and potential stigma associated with the monitoring technology. An increase in wearable devices used outside of the clinical environment, such as those used for monitoring chronic illnesses, could result in previously unseen patient concerns surrounding their use in a social setting.<sup>12</sup> Discretion and societal acceptance should be considered throughout development, particularly whilst these technologies are in their infancy.

Using well established consumer health technology, such as Fitbit and the Apple Watch, allows us to address some of the issues surrounding social stigma whilst also limiting the amount of active data entry required by the user. For example, Tactio Health<sup>13</sup> automatically syncs with third-party platforms, such as Fitbit, MyFitnessPal and the SmartOne spirometer, to provide health trends, risks alerts and other indicators on a concise dashboard, requiring less user input. The Abbott FreeStyle Libre system<sup>14</sup>, which already provided a more discreet way of monitoring blood glucose than using lancets, can now be scanned with a smartphone rather than a dedicated scanning device that could be seen as conspicuous by the user.

Accounting for the rapidly evolving technology and communications landscape within product development gives us the opportunity to adopt interfaces that non-medical users are familiar with. An example of this is the use of Amazon Alexa to assist with healthcare activities through the development of HIPAA-compliant medical skills.<sup>15</sup> The use of natural language interfaces has the potential to reduce the initial learning curve to using monitoring technology and providing different interface options could help address the variety of user capabilities and environmental characteristics.

## 3.2 MORE INSIGHT AND PREDICTIVE POWER

Monitoring can provide data and help to uncover trends, but it is ultimately up to clinical staff to interpret these within the context of the overall health of patients, and to decide the desired treatment pathway. Patterns of critical illness, however, can be highly complex and take years of training and experience to quickly and reliably understand.

Furthermore, caregivers often have to process and understand large amounts of data. It has been estimated that up to a million data points can be generated each hour from a single critically ill patient.<sup>16</sup> The facts available per clinical decision already saturate human cognitive capacity and the data is projected to continue to rise exponentially.<sup>17</sup> There is a fundamental need to find ways to analyse and present data in a way that is meaningful, reduces cognitive load, and that can support timely clinical decisions and resource prioritisation.

Different approaches are used to help in the interpretation of the patient data and to turn it into actionable information. At the simplest level this can be the provision of decision support systems based on clinician defined care pathways.

A good example of this is the Vital Sync™ CDS platform from Medtronic. This is a software platform with modules that calculate and report early warning scores, ventilation weaning readiness scores and spontaneous breathing trial outcomes. These workflows are based on published consensus clinical approaches, but the system does allow the hospital to adapt protocols to their own requirements.

We are now seeing the emergence of more sophisticated systems based on algorithms that are derived from physiological data and models (see inset). These may be decision support solutions (what should I consider doing?) or predictive analytics (what is probably going to happen?). Such systems requiring a clinical response are viable commercial stepping stones to automated control systems.

## CLINICAL DECISION SUPPORT AND PREDICTIVE ANALYTICS CAN PROVIDE POWERFUL SUPPORT TO THE CAREGIVER

An example of an open loop control system is the Space GlucoseControl System (B. Braun). The device calculates a recommended insulin dosage rate to maintain glycaemic control in critically ill patients, as well as determining a blood glucose measurement interval. Both interventions require action from the healthcare professional to implement.

Edwards Lifesciences has taken a different approach, providing the user with a prediction of the likelihood of an adverse event, but leaving them to determine the best course of action. The Acumen Hypotension Probability Indicator (HPI) uses an algorithm to predict the percentage risk of an imminent hypotensive event from trends in a patient's haemodynamic measurements. The user can drill down to look at the underlying indices to understand the likely underlying physiological causes and infer an appropriate intervention to avert the predicted adverse event. Eventually we can see the potential for such systems to achieve a level of reliability that would allow the automation of intervention to be achieved.



CDS solutions are also being applied to helping prioritise the use of finite healthcare resources. A recent example from Raita et al<sup>18</sup> from Harvard Medical School demonstrates that triaging systems underpinned by machine learning are capable of more accurately differentiating and prioritising critically ill from stable patients, enabling efficient allocation of emergency department resources and potentially improving outcomes.

The technologies that will enable progression of CDS and closed control systems include data analytics and AI for algorithm development. AI techniques are also being developed that can help generate more balanced datasets for use during the algorithm development phase. Whether data is processed directly on the device or transferred to the cloud first is an important consideration, particularly where fast response time, cost, power management or independence from connectivity are key aspects of system performance. In these cases, efficient algorithms that can be deployed directly on low-power devices (edge computing) will have a considerable advantage over cloud-based solutions.

Explainable AI will also be important for the acceptance of these technologies by regulatory bodies, as there may be considerable resistance to handing control over to a 'black box', that makes decisions without providing an underlying rationale. The increasing availability of predictive power and CDS solutions is likely to spark a debate about the potential

for de-skilling care providers and the possible risks of making them more reliant on the output of monitoring technology, and less on the raw data.

## 3.3 EMERGENCE OF NEW MODALITIES AND USE OF BIOMETRICS

Clinical decision making is based on a multi-modal "complete picture" view of the patient. The patient is not managed against a single measurement or variable, and trends are often as important as point values. New monitoring modes will provide a richer picture of the patient, both in terms of new quantities measured as well as the ability to frequently or continuously monitor things which are currently only available as point measurements.

Many measurements and assessments, from blood pressure to sedation scales, are undertaken on an intermittent basis, often because continuous monitoring has historically been impractical, or these are subjective assessments. The period between readings is driven from a clinical perspective of what is a practical and reasonable interval. This can result in delays in identifying and responding to a significant change in patient condition.

For example, the National Early Warning Score recommends checking a range of key indicators on vulnerable patients between every 4 to 12 hours, depending on the level of concern for the patient.<sup>19</sup> Continuous monitoring can detect a critical value more quickly than such an intermittent approach and has the potential to identify the underlying trend at an earlier point still.

Direct, frequent monitoring of gold standard markers, such as those requiring blood tests, may not be particularly feasible, and in some cases measurement of correlated biometrics is suitable. An example of this is Cambridge Consultants' Verum platform,<sup>20</sup> a system for the monitoring of physiological, contextual and behavioural data in order to infer states. Verum demonstrates how chronic stress can be measured and monitored throughout a clinical trial, to maximise the likelihood of clinical and commercial success. The system uses a combination of electromyography and voice analysis to measure an index of stress, with a strong degree of correlation to reported stress levels.

Enabling technologies for new monitoring methods will depend on the property that is being monitored, but non-contacting or non-invasive technologies are likely to be key. AI is also likely to play an important role in the development of monitoring solutions based on biomarker correlates. In the case of Verum, machine learning techniques were used to correlate each of a wide range of potential monitoring modes to stress levels and to determine which were the optimum combination of sensor types.

### 3.4 INTEROPERABILITY

The introduction of EHRs (electronic healthcare records) in the 1960's was designed to collate an individual's health data in a central place, providing doctors with a full clinical picture of the patient for efficient care coordination. However, due to the lack of mandatory interoperability standards, each EHR provider built and maintained their own data silo, often on premises and accessible only to hospital or even department-specific practitioners directly enrolled in that program. This complexity and prevalence of disparate EHRs, all unable to communicate and transfer data among each other's platforms using APIs (application programming interfaces), led to fragmented patient records spread across many different systems, that in turn led to inefficient diagnosis and treatment regimens across the entire patient care pathway.

The new FHIR<sup>21</sup> (Fast Healthcare Interoperability Resources) standards were developed by Health Level Seven International (HL7), a healthcare standards organisation, to

facilitate interoperability between legacy healthcare systems. The goal is to make it easy to provide healthcare information to providers and individuals on a wide variety of devices, from computers to tablets to smartphones. It was also meant to allow third-party application developers to provide medical applications that can be easily integrated into existing systems. When Apple launched its Health Records in 2018 it incorporated FHIR – and nearly 150 hospitals have signed on to support the tool in the first year.

At the same time, EHR makers, such as Allscripts, athenahealth, Cerner, eClinicalWorks, Epic and Meditech, have developer programs that use FHIR and open APIs to enable third parties to write software that uses their electronic health record platforms. Note that the 21st Century Cures Act requires certified EHRs to have open APIs.

We are now at a tipping point, with initiatives such as the backwards compatible FHIR 4 standard and the finalised information blocking rule from the US Department of Health and Human Services. The stage is set for notable advancements in health information exchange that will allow for RPM solutions to be fully integrated into the patient record.

However, technology barriers are not the only obstacles in the way. There remains a cultural mind shift that is required by practitioners, industry and patients alike when it comes to data transparency, sharing and security. This may to some extent be generational but approaches such as the blockchain initiative Mint Health are also essential to incentivise patients to upload and share their own genomic, health and wellbeing data. Integrating this into the EHR should help the clinician to make informed decisions. Outside RPM data needs to interact with the native information to provide insights, such as CDS.

### 3.5 REDUCTION OF INVASIVENESS

Highly invasive monitoring techniques are already used in critically ill patients if the resulting data is very important to helping manage the patient and if there is no alternative. However, there is always a drive to reduce invasiveness to lower the risk of harm to the patient.

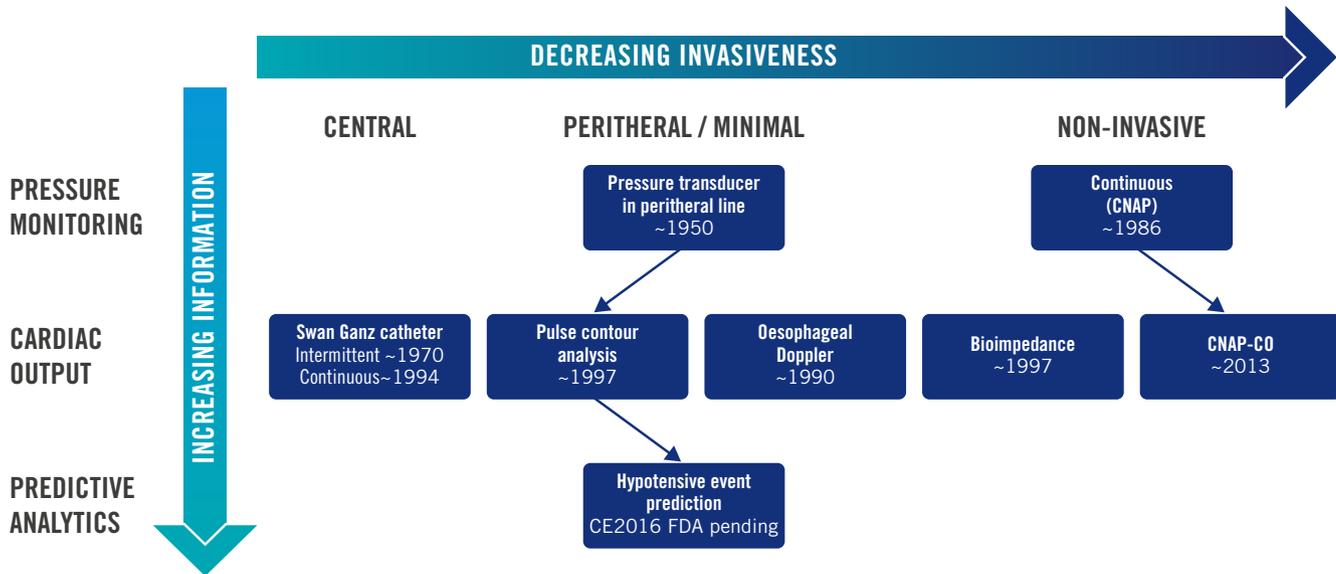
In addition to risk reduction, less invasive monitoring often brings other benefits, such as being easier to deploy, taking less staff time to set up and skill to use and reducing the amount of training that is required. Furthermore, a change in the risk/benefit ratio allows monitoring to be considered for a wider group of patients, potentially extending benefits to lower acuity wards or out of hospital settings, where invasive monitoring is not normally used.

An excellent example of this overall trend is the progression of continuous cardiac output monitoring (Figure 1).

Over the last two decades there has been an almost complete shift from the use of the centrally placed pulmonary artery catheter to systems carrying out pulse contour analysis on peripherally invasive arterial pressure traces, or those using a doppler probe placed into a natural orifice (oesophagus). Minimally invasive monitoring has taken over most of the pulmonary artery (PA) catheter market, but also helped

to expand the use of cardiac output monitoring in patients that previously would not have been monitored, due to the invasiveness of the PA catheter.

More recently we have seen the introduction of pulse contour analysis from non-invasive finger cuff pressure monitoring sensors. While non-invasive monitoring still suffers from motion artefacts, it is an attractive option for monitoring patients during surgery, where placing an invasive arterial cannula would be inappropriate.



**Figure 1:** Development of continuous haemodynamic monitoring in terms of increase in information and decrease in invasiveness. Dates are approximate market introduction dates of commercial products.

## MONITORING IMPLANTS

One area bucking this trend is the use of implants for accurate and convenient long-term monitoring. An example of this is implantable cardiac monitoring (ICM) devices, which can be used to diagnose conditions such as atrial fibrillation. In some patients, the condition is suspected but episodes are relatively infrequent and unlikely to occur during a routine checkup, but the potential consequences are stroke or death. Continuous monitoring over months using conventional ECG electrodes would be highly impractical, so an implant and associated reader are a more acceptable option. A significant number of researchers are working on implants to monitor and help manage other chronic conditions, particularly diabetes, where an implant could be a preferable alternative to finger prick blood glucose measurements or subcutaneous needle sensors.



The use of less invasive approaches usually comes with a trade-off against accuracy or reliability. This may be less of an issue in lower acuity settings, where the trend is important, and an offset may be tolerable. Advances in signal processing techniques will narrow the gap in reliability between minimally invasive monitoring approaches and their gold standard invasive counterparts.

Other enabling technologies for less invasive monitoring techniques will depend on the property to be monitored. Consumer electronics trends are driving the availability of low-cost components including accelerometers, cameras, WiFi chipsets and microwave doppler sensors, which have all been used to demonstrate feasibility of physiological monitoring.

### 3.6 REDUCED PATIENT CONSTRAINT

Cables from connected monitoring sensors can be a great inconvenience both to the patient and to the healthcare staff. They can constrain the patient, making limb movements and turning over difficult or uncomfortable and can result in user errors, such as accidentally detaching cables: a fundamental usability issue.

From this perspective, wireless connectivity of on-patient sensors is attractive and wireless monitoring patches have been developed that are currently targeted for use in lower acuity care areas. These typically monitor physiological measurements, such as heart rate, respiratory rate, temperature and movement. Whilst being wireless overcomes the issues associated with cables, they can pose challenges of their own, such as power management and robustness of connectivity.

In critical care, where monitoring is used the most intensively, clinical practice is moving towards lighter sedation and earlier mobilisation. There has not, however, been adoption of wireless technologies for monitoring devices. Potential concerns include data loss or corruption over the wireless link, confidence in pairing patient readings to the right monitor and practical solutions for maintaining power in the sensor. Advances in robust wireless connection, antenna design and wireless power delivery all have the potential to challenge the conventional thinking in this space.

Non-contact monitoring technologies also have the potential to mobilise patients and are particularly well suited to lower acuity settings, where the wireless patch may not be a cost-effective solution to pick up the relatively low incidence of a seriously deteriorating patient. For example, Hill-Rom

recently announced the integration of EarlySense's monitoring technology into their hospital beds, which monitors the patient's pulse and respiratory rate and movement, using a piezoelectric sensor sited under the mattress.<sup>22</sup>

Measurement of a range of physiological parameters has been demonstrated with a range of non-contact methodologies. Optical and image processing and other active and passive electromagnetic measurement techniques have been used to measure respiratory rate, oxygen saturation, temperature, heart rate, heart rate variability and pulse transit time. While challenges remain to translate these into robust, reliable medical devices, these technologies have the potential to change thinking on how patients are monitored in lower acuity clinical settings.

### 3.7 BETTER ARTEFACT REJECTION

One of the risks associated with monitoring is when poor or spurious signals cause false alarms. The nature of vital signs monitoring means that there is a regulatory drive towards audible alarms, even if the alarm indicates 'no signal', rather than a physiological alarm condition. The resulting noise can be a significant problem, both as a distraction to care staff and creating a stressful environment for the patient. Perhaps more worryingly, there is also the potential for false alarms or alarms that are perceived to be unnecessary being silenced or ignored by HCPs, and the sheer quantity of alarms masking those which are of most importance.

Advances in signal processing techniques have made significant improvements to the robustness of many monitoring technologies. However, the trend towards less invasive measurement means that further progress is required, because these technologies tend to inherently have a poorer signal-to-noise ratio.

With the trend to make patients as mobile as possible, motion artefacts are likely to be a key and growing issue. Further improvements can be based on additional sensor inputs. Wearable devices usually incorporate several different sensor types to monitor a range of physiological or patient behaviour variables. Fusion of the data from multiple sensors can result in more robust algorithms or be used to identify periods when confidence in data integrity is low, to suppress false reporting.

## 4 THE OUTLOOK FOR MONITORING

### 4.1 MONITORING OF THE FUTURE

Patient care will be transformed in the next 10 to 15 years and new types of products, services and applications will emerge. In this environment, patient monitoring will play a central role in helping to enable the actual transformation. For patient monitoring companies to remain competitive in this changing landscape they will need to adapt business models and product roadmaps.

We expect monitoring of the future to be more flexible and to reflect the needs of value-based healthcare provision.

Required improvements in the quality of care and the avoidance of adverse incidents will drive growth in the use of monitoring in all areas of the hospital. Continuous monitoring of patients' condition while in the hospital will make it easier for treatment teams to respond to any sudden or gradual deterioration. Although the number of parameters and patients measured will increase dramatically, advances in monitoring capabilities and careful user-centred design will make this process seamless for healthcare professionals. Advances in analytics and CDS will be necessary to counteract staff becoming overwhelmed by the rising volume of data.

Patients will be mobilised early and further reduction in hospital stays are expected. This will not only be driven by the quality of care in the hospital but also by enabling good quality care away from hospitals. Monitoring technology will allow a more seamless and fast transfer of stable patients to home. Access to data will allow the same therapeutic team to be responsible for their treatment along the care path, something that will allow greater levels of treatment continuity.

Technology will allow clinicians to be more efficient. Improved monitoring systems, with more accurate alarms, will minimise time wasted while telemetry will permit them to 'attend' patients remotely. Integrated data systems and data analytics will enable access to the right patient's information at the right time. Moreover, technology will allow more efficient knowledge transfer between therapeutic team members and even access to other experts who may not be on site. It is also worth noting that the collection of large amounts of data, often longitudinal in nature, will provide an opportunity to identify trends, patterns and correlations at both the population level and at the systems level within a patient, benefitting treatment regimens and clinical decision support.

### 4.2 STAYING COMPETITIVE

While products and services need a continuing focus on clinical performance and how this impacts the delivery of life saving and sustaining services, companies will also need to focus on improving the patient and caregiver experience. Device manufacturers will need to understand the value of earlier patient mobility, of less invasive monitoring and of more agile care environments. Unless they go through this cultural change it is likely that they will face intense competition from the technology companies that know how to exploit data from devices and can use this to demonstrate improved outcomes and gain reimbursement.

Companies will need to adopt technologies that can deliver systems and devices that redefine usability. Care of the future will be more agile and patient monitoring systems more easily deployable, particularly if this means converting the home to a care environment. Similarly, this agility needs to be supported by access to data management platforms which share a high level of integration. Models of workflow management and remote support that optimise the use of healthcare staff without compromising the quality of care need to be developed. Only then will they overcome the challenge of building continuity across multiple hospital sites and with out-of-hospital care.

The companies best placed to make the most of this changing environment are those with a robust digital health strategy that can navigate the transformational changes inherent in moving from offering monitoring as a product, to monitoring as part of a broader service offering. Building out the digital ecosystem to take advantage of a wider set of data streams and products requires partnerships with a range of non-traditional vendors and companies that give access to a broader set of capabilities, spanning technical, organisational and clinical domains.

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