

The future of individualized cardiovascular care: how wearables could be integrated to improve outcomes

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Personalized medicine is a concept all clinicians must strive to deliver. Recent advances in technology increasingly offer new opportunities to personalize care, not least in cardiovascular medicine. Health trackers and wearables are technologies in an explosive phase of development. They allow accurate and continuous measurement of bio-data, recorded and analysed using apps and mobile devices. However, although there is huge potential, most physicians and healthcare organizations are yet to realize the value of integrating wearables into routine clinical practice. We discuss how this state-of-the-art technology can support patients in making meaningful lifestyle changes and revolutionize the future of cardiovascular medicine.

Introduction

Personalized medicine should not be a new concept to cardiologists. Physicians are required to focus on patient variability and tailor treatment accordingly. Thrombolysis doses are calculated by weight, stents chosen according to vessel size, and beta-blocker doses titrated to heart rate and blood pressure. Simple treatment decisions about therapies are part of routine practice in cardiology. It is expected that clinicians should identify a patient's needs and wishes before embarking on a new therapy or investigational strategy. Yet, in contrast, there has been an increasing focus on the fallibility of decision-making, the role of heuristics and the superiority of algorithms. This has in turn driven a view that replacing individual decision-making with algorithms is the future. How should we square these apparently conflicting positions?

Major advances in science and technology, not least in genetics and genomics, may offer further insights into individual responses to common biological insults. Early insights within the field of genomics have led to some

startling insights, but also an increasing understanding of the complexity in translating genetic variability into individualized care.¹

Within cardiology, it is now clear that hundreds of mutations in the low-density lipoprotein receptor are responsible for familial hypercholesterolaemia, for example, and further insights into the 'omics' (*genomics*, *transcriptomics*, *proteomics*, and *metabolomics*) of the complex human lipid handling system promise to lead to deeper understanding.²

Novel genetic technologies like next generation sequencing, used to sequence and quantify RNA or DNA, now present a plethora of data. Understanding the biological relevance of such expansive data sets carries major potential but is not without risk. Interpretation is time-consuming, expensive, and requires high-level expertise. Furthermore, benefits are rarely guaranteed in advance and, as with all large data sets, discerning real from random patterns and trends is critical. The larger the volume of data at hand, the higher the risk of false positives and therefore incorrect assumptions. Finally, there remains a fundamental mismatch between the ability to make population-based recommendations and the challenge of extrapolating these findings to individuals.³

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It may be that ‘wearables’ offer the opportunity to close this gap. Wearables are designed to capture large amounts of bio-data, in an unobtrusive way, so the user need not spend time physically journaling or recording it themselves. The wearables industry is in an explosive phase of development. Alongside the overwhelming penetrance of smart phones, recent years have seen the advent of multiple fitness trackers and smart watches. In this review, we discuss how implementation of such novel technologies has the potential to impact global care of cardiovascular patients profoundly.

Cardiovascular health is significantly influenced by three basic facets of health: exercise, diet, and sleep. These can all be measured on a granular level by wearables.

The argument for wearables and health trackers

Perhaps the most impactful development in wearables is ‘fitness trackers’. These devices have evolved far beyond simple step counting and are capable of continuously tracking cardiovascular parameters such as heart rate, heart rate variability (HRV), resting heart rate, and peak heart rate.

Such data would previously have only been available to the clinician via formalized investigations such as a 24 h electrocardiogram (ECG) recording. This raises several new and important questions about what to do with these data. Firstly, how is it interpreted, and what does it mean? Definitions of normality and importance of temporal trends in these metrics remain poorly defined. Once an issue is identified, where does the responsibility for action lie? To be effective, the output from wearables needs to be easily understood and be able to effect behavioural change in a highly individualized fashion. This in turn raises the question as to how goals should be individualized, for example, a target step count of 10 000 may be appropriate for a previously sedentary middle-aged adult, but insufficient for an aspiring athlete, and excessive for an 80-year-old heart failure patient with NYHA 3 dyspnoea.

This brings into focus the ‘glass ceiling’ between wellness and health. The beneficial effects of exercise, diet, and sleep are often espoused by physicians, but rarely prescribed and adhered to with the same vigour as ‘life-saving’ medications or interventions. It may be that compliance is easier to achieve with medications, but also easier to prescribe than something as nebulous as ‘take more exercise’ or ‘sleep better’.

This may have been due to impaired self-reported symptom outcomes. With continuous data extending beyond exercise into sleep and metabolism, the role of the healthcare professional is more blurred than ever. Many chronic diseases, including coronary artery disease, cancer, and inflammatory disease are consequent on environmental changes to which humans are maladapted. Allostatic mechanisms which previously kept us safe from predators and encouraged gorging on autumnal fruit have not evolved to enable adaptation within today’s environment of ready availability of processed food.

Wearables may extend the reach of allostasis, providing the end-user an ‘extended brain’, which may encourage better food and exercise choices by biofeedback.

Wearables: a myriad of metrics

There are multiple wearables with the ability to track many different health and activity metrics. Currently available devices are worn on the fingers, wrists, arms and chest, and subcutaneously in the case of continuous glucose monitors (CGMs). Although initially focused on activity tracking, more recent devices are capable of monitoring sleep, temperature, energy expenditure, multiple cardio-respiratory parameters, and even dynamic metabolic physiology. The industry, which largely emanated from Silicon Valley, associated with a movement known as ‘the quantified self’, has benefited from the 21st century emphasis on health and self-improvement.^{4,5} Self-monitoring devices have expanded in number and sophistication and are marketed not only as a tool for serious athletes, but also for daily health monitoring and lifestyle improvement. It is only in recent years that physicians have become more aware of their potential utility in cardiovascular medicine, in some cases prompted by the presentation of unexpected data by their patient. It is perhaps now unavoidable that wearables will become a routine facet of modern-day healthcare.

Although activity trackers such as Fitbit were many people’s introduction to this form of technology in around 2009, the idea of step counting is not novel. It is recorded that Leonardo Da Vinci had sketched an early pedometer to record the footsteps of Roman soldiers in the 15th century, and US President Thomas Jefferson had worn an early version of a step tracker some years later. It was in the 1960s, however, that Yamasa, a Japanese technology company produced the first modern-day pedometer after a local physician had suggested that the nation’s health would be greatly improved if everyone walked 10 000 steps a day. This was in fact how the oft quoted target of 10 000 steps is thought to have been conceived: far from an evidence-based recommendation.

In parallel to Fitbit’s wrist-worn devices, several other technology companies had begun to develop and popularize activity trackers, combined with the strength of ever-developing machine learning [a.k.a. artificial intelligence (AI)]. Apple incorporated a step counter into the early iPod nano and iPhones, but subsequently has launched a Health app which has evolved to utilize motion data and multiple other metrics to derive sophisticated outputs and scores. For example, a ‘walking steadiness score’ estimates an individual’s risk of falling in the next 12 months and if the risk is perceived to be high, then notifications and advice are delivered to the user. The Apple Watch is one of multiple devices which feeds into the Health app, and is capable of monitoring cardio-respiratory biometrics and vital signs, and producing a diagnostic quality ECG. Similar to Health from Apple, apps like Google Fit present metrics related to sleep, exercise, calories expended, and overall wellness, each offering advice and even coaching when shortcomings are detected. Google Fit awards one ‘Heart Point’

for each minute of moderately intense activity and combines graphically presented data with notification-type prompts to encourage users to meet the World Health Organization target of 150 min of exercise per week.

In elite sport, the benefits of wearable trackers were realized even before the popularization of health apps. As opposed to more general indicators of wellness, dedicated sports devices sensitively record cardiovascular parameters centred around heart rate and performance. In cycling, metrics recorded during activities such as speed (kph), power output (watts), and cadence (r.p.m.) are integrated with physiology to very sensitively detect trends in performance. The feedback loop here is clear to appreciate: if the athlete's power output is increasing for the same given heart rate, then performance is improving and their training regime working.

The cross-over between sports performance and health is greater than ever, and athletes are learning to focus on recovery as much as performance, utilizing metrics such as HRV, sleep scores, and 'readiness' levels. Close supervision of diet, rest, and sleep is biometrically logged and monitored by data being continuously uploaded to the internet cloud.

This emphasis on wellbeing has spawned another generation of wearables, also worn by serious amateurs, and increasingly a health-conscious general population. Oura Ring has now released a third version of their technology purportedly capable of measuring oxygen saturations, to add to the existing components that formulate a 'readiness' score, informing the user of how fit they are to exercise on any given day.

In medicine, the use of wearables has not fully taken off yet, although the potential clearly exists. Disease-specific monitoring devices like CGMs have revolutionized how patients with Type 1 diabetes manage nutrition and insulin, with data emerging on applicability within Type II diabetes.⁶

Instigating behavioural change

With swathes of data now continuously collected by wearables, what value is added to the individual and to the population? Though intuitive benefit might be inferred, there is mixed evidence as to whether wearables make a significant difference to patient outcomes, and some concerns about the reliability of using consumer wearables in healthcare.^{7,8} Yet, a growing body of evidence does exist to demonstrate effective behavioural change in exercise and nutrition. It is likely that with the right model of implementation this can be translated into meaningful health benefits.⁹⁻¹²

Behavioural change is difficult to effect within a traditional clinical interaction. Although cardiac rehabilitation is acknowledged as an effective intervention, compliance remains suboptimal with lifestyle recommendations.^{13,14} Wearables may improve adherence and lead to sustained behavioural changes. Increasing levels of engagement with self and wellbeing are likely to lead to better outcomes, as evidenced by the truism that what is measured is actioned. When patients feel part of

the decision-making process, it leads to an augmented sense of responsibility.^{15,16}

Data are typically presented in the form of graphs and charts using mobile or online apps. The manner in which the message is relayed to the user is critical in ensuring engagement. Howard Zisser of Supersapiens, who have integrated a continuous glucose monitoring system with app-based performance analysis, says that the interface must be 'grockable'. This means that the output must be immediately and intuitively digestible to the user. The volume of data is less important, but measurements must be relatable: 'personalized'.

Furthermore, it must be actionable. While myriad of metrics have been derived, only meaningful ones need to be emphasized. While body fat percentage is an excellent metric to target, bone mass is not particularly helpful for this application, and thus not worthy of repeated measurement.

Of course, most patients or users are not educated in terms of human physiology, so how does wearable technology overcome this? Oura Ring and Whoop Band are both products which use algorithms to incorporate HR, HRV, sleep, and activity levels to produce an overall fitness or readiness score. While most users would not understand the physiological relevance of individual components (e.g. HRV is complex), an overall readiness score is more relatable. Absolute values in HRV are difficult to interpret, and it is machine-learning technology algorithm that recognizes deviations from an individual's usual pattern. When the HRV trend is significantly different, the readiness score accordingly changes.

To induce change based on these scores, each metric given has to then present an algorithmic course of action leading to improvement: a low sleep score is remedied by earlier bed-time and improved sleep hygiene; a low activity score is improved by encouragement to increase exercise levels; and a low HRV may be improved by rest and recovery. With each measurement and action follows further measurement and feedback. Improvement is then rewarded by a better score, congratulatory messages, and even social media interaction, which is shown to be a motivating factor.¹⁷

Thus, a feedback loop is formed between the user and their data. Data are continuously accumulated with little maintenance, and the effects of lifestyle changes can be monitored. App-based algorithms incorporate many of the critical processes that behavioural scientists deem necessary to institute behavioural change. 'Self-monitoring' aspects such as prompting, monitoring, personalized messages, and goal setting are automatically performed by the software, and consistently work to build on the core 'self-determination' of the individual which is crucial for maintenance of change.^{18,19}

Augmented allostasis

Wearable and app-based coaching represent an exciting and novel means to access the well-validated benefits of optimal exercise, nutrition, and sleep. However, the basic principles which explain their efficacy likely relate to

inherent properties of the human mind, well studied in behavioural science.

'Allostasis' is the brain's ability to interpret environment and react accordingly, to maintain energy balance or 'homeostasis'. Changes in behaviour are instigated by predictions made based on senses, and actions taken to preserve energy and survive.^{20,21} In evolutionary terms, organisms with the best allostatic mechanisms would be more likely to prosper as they successfully evaded predators, gathered food, and reproduced. When a predator is recognized, the brain responds by internally triggering the autonomic, endocrine, and cardiovascular systems. The awareness of the resultant sensations and more generally of one's own physiological condition is referred to as 'interoception.'²²

Modern-day humans rarely have to flee predators, and in developed nations food is plentiful. The evolutionary cycle has lagged behind the changes in food environment with allostatic mechanisms poorly adapted to such a surfeit of energy dense processed food. Perhaps apps and wearables can bridge some of this gap? Metrics of activity levels and calories burned can indicate optimum energy expenditure on an individualized level; markers of fitness like resting heart rate and VO_2 max can feed back on the effectiveness of exercise; and CGMs, calorie trackers, and weighing scales can monitor metabolic progress. The addition of wearables could be seen as an augmentation of allostasis or an 'extended brain'.

Enhancement of interoception may also help. With time, users become more aware of bodily sensations and what it means to their wellbeing. It is a known phenomenon that athletes learn to predict heart rate during exercise, and similarly with sleep tracking apps, the sensation of good or bad sleep becomes more recognizable. It may become possible to better understand bodily sensations which correlate with wellness scores and commit to positively ameliorate them. Any long-standing user of My Fitness Pal would attest that the relative calorie contents of foods is well committed to memory, and even when separated from the app interface, their previous training is still mentally accessible. In summary, wearables may enhance allostasis and interoception.

Integrating wearables into contemporary practice

Incorporation of wearables and associated technologies into routine healthcare carries huge potential. Smart phones, watches, and other wearables are both ubiquitous and accessible. To combine the improved engagement, adherence, and behavioural change possible with wearables with the validated benefits of exercise, weight loss, and sleep could revolutionize primary and secondary prevention of cardiovascular disease. While there are a growing number of examples in the literature demonstrating clinical use of wearables in small and well-defined patient groups, there are significant barriers to greater penetrance on a population level.¹⁰

As wearable devices are produced by multiple commercial manufacturers, data are not uniformly presented or

archived and a novel mechanism to incorporate it into patients' healthcare records would be needed. Vast amounts of physiological information already exist on proprietary clouds and on individuals' devices, but this would need to be channelled electronically to the physician, and then analysed. For individual patients, this could be as simple as performing a download for analysis, just like having an ECG done on the day of a clinic. The future will doubtlessly require physicians to be able access this data to truly personalize care.

On a larger scale, wearables have the potential for use in national screening exercises, and this has already been demonstrated in the Apple Heart Study. Their impressive sample size ($n=419\,297$ participants) was possible because of the massive penetrance of smart watches within the US population, along with the substantial research resources available in such a setting.²³ Clearly, opportunities now exist for similar applications in routine healthcare, too. Unfortunately, the health economics of such a programme are complex, and in already resource-poor public healthcare systems perhaps unrealistic, especially before long-term population-based health benefits have been definitively demonstrated.

In addition to the high financial cost of incorporating wearables into routine clinical practice, there are several other potential limitations to consider. First is the issue of false positives, and the resultant additional cost this would incur. As with any screening tool, specificity is traded with sensitivity, and wearable systems are presently not well developed for this purpose. The Apple Heart Study demonstrated that of the 450 participants who received an AF notification and also returned an ECG monitoring patch, only 36% were actually shown to have AF. At present, the benefits of increasing rates of diagnosis would have to be balanced with the feasibility of providing additional tests and consultations. Sophisticated AI algorithms and improvement in wearable devices will surely continue to close this gap in the coming years.

For the individual, wearables remain a choice, and in all cases are worn at the user's discretion. In general, this engenders a positive impact on attitudes towards health and as discussed above carries the potential for substantial self-improvement. However, a less healthy relationship with such extensive and granular data is possible, and as parameters and read-outs become more sophisticated, interpretation becomes more difficult. For example, variation in a metric such as HRV may or may not be physiologically important; but oftentimes this would be scientifically unclear, and how should the lay person be expected to act on it with confidence? As cardiologists, we have already become familiar with the new clinical problem of an elevated heart rate seen on a wearable, which is usually a physiological response not worthy of concern. For patients, it is natural that anxieties will emerge, and for some, this could in fact be deleterious to their overall health. A recent study of affective responses to wearable devices was quite reassuring in this respect, demonstrating that although users commonly reported anxiety when separated from their devices, the overall effect of wearables on mood was positive.²⁴

Conclusion

Truly personalized medicine is a concept all clinicians must strive to deliver. Patients are individuals, with unique characteristics, needs, and patterns of disease. Novel technologies have the potential to revolutionize disease prevention and management by effecting meaningful and sustainable behavioural change in individuals.

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Data availability

The data that support the findings of this study are openly available in PubMed.

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