The Royal Academy
Of Engineering

Vodafone Lecture Series

Mobile Telecommunications and Networks

Monday, 22 February 2010

Held at:

The Royal Academy of Engineering
3 Carlton House Terrace
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SW1Y 5DG

Keynote speaker: Lionel Tarassenko
Director of the Oxford Institute of Biomedical Engineering

Royal Academy of Engineering

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Professor Michael Walker: Good evening everyone. Welcome to the Royal Academy of Engineering. My name is Michael Walker and I am going to be hosting the session this evening. [*Housekeeping notices*] This evening is the first of a series of three lectures and the series is the fourth in a set of annual lectures which Vodafone and the Royal Academy of Engineering have been hosting for the last three years. Each year we have three lectures. In the past they have been quite technical. This year we decided we would look not so much at the technology of mobile communications and networks, but at the applications. We have three lectures. We have one following this, one which will be on intelligent transport systems and another which will be on social networking. Tonight the focus is on healthcare, mobile health.

I am really pleased that Lionel Tarassenko agreed to come and give the lecture this evening. As most of you in the room will know, Lionel is the Director of the Oxford Institute of Biomedical Engineering. For the past 20 years, he has done research in signal processing and its applications, in particular to diagnostic systems, medical applications being one of these, but not exclusively. He has done a lot of work for the aerospace industry as well, diagnosing things that could go wrong with large engines.

He is, in my opinion, the most well qualified person in the country to come and talk to us about mobile health this evening, so I am really delighted he was able to accept this invitation. Lionel, if you would like to take the podium, we look forward to your talk.

[*Applause*]

mHealth: Mobile Technology for 21st Century Healthcare
Lionel Tarassenko
Director of the Oxford Institute of Biochemical Engineering

Thank you very much Michael. Thank you to Vodafone for sponsoring this lecture. My links with Vodafone go back to the pre-history of Vodafone before it was even called Vodafone. I worked for a company called Racal in their research lab, Racal Research. I am delighted that my first boss ever when I left university is here tonight, Keith Thrower, also a Fellow of the Royal Academy of Engineering. This time goes back probably longer than either of us cares to remember, when I started as an electronic engineer working in communications, speech coding, and signal processing. Here we are 30 years or so later at a Vodafone-sponsored lecture, and I was absolutely delighted to accept Professor Walker's invitation to come and talk tonight. My aim is to try and convince you that mHealth is for real; it is not just hype. For the next hour or so, I am going to take you on a guided tour of mHealth and I will have failed in my mission if you are not convinced at around about half past seven that mHealth is indeed here to stay.

mHealth, a multidisciplinary venture – clinical and technical collaborators

Mobile Health is a multi-disciplinary venture and I thought that I would thank my many collaborators at the start. The first of these are my clinical collaborators in Oxford, mostly but not exclusively in the Department of Public Health and Primary Care. Then there are my research students and Research Assistants, some of whom are here tonight. Because of my passion for the technology to be used by patients, we have spun out two companies from my research group in the last eight years: t+ Medical and Oxford BioSignals, now merged into one company (OBS Medical). Some of the people who have helped me produce some of the results that you will see tonight are included on this slide.

Quite apart from this lecture, I have worked with Vodafone in the field of mHealth since 2003, when their Corporate Social Responsibility Foundation sponsored the first diabetes trial that I will describe later on. Thank you to Vodafone not only for sponsoring the lecture, but also for helping to kick-start mHealth in the UK six or seven years ago. I am also grateful, of course, for the funding that is required to do any research. I am delighted that the Chief Executive of the Engineering and Physical Sciences Research (EPSRC) is here, Professor David Delpy, a biomedical engineer, therefore very much at home I hope. The Wellcome Trust are also funding, with EPSRC, our Centre of Excellence in Personalized Healthcare. Additional research funding has come from the National Institute of Health Research, (NIHR) – a big thank you to all research funders for making it possible for mHealth to happen in Oxford and elsewhere in the UK.

Overview of Lecture

I want to construct my argument so that by the time we get to the final bullet point you will agree, looking at it from the patient, the healthcare professional, the healthcare provider (the NHS in this country), that mHealth is a technology which is here to stay.

25 years ago: the launch of the UK cellular telephony service

I will start with a bit of history and of course, most of you will know that mobile phones themselves are a very recent phenomenon. It is only 25 years ago that the UK cellular telephony service, as it was called then, was launched. Some of you may know that Ernie Wise made the first call using a mobile telephone from London back to Vodafone headquarters in Newbury in January 1985, almost exactly 25 years ago. In those days, mobile phones were car phones, because you needed the car to support the weight of the mobile phone's battery.

10 years ago – mobile phones and health

Dr Diane Sullivan from Vodafone, who is in the audience, will not thank me for putting this slide up, but 10 years ago mobile phones and health had quite a different connotation. I traced some of the articles that were on the web or in the written press 10 years ago, all about the health risks of cell phones in the States or mobile phones in this country. This clip from CNN says that "Chief Information Officers need to make sure that cell phones are operated in a manner that reduces the health risks associated with radiation or face the legal consequences". That was very important in the US with its litigation culture.

That is the context in which mobile phones were being discussed as far as health was concerned just 10 years ago. Of course you will all remember that you were not allowed to take your mobile phone into a hospital; the use of mobile phones was banned inside hospitals because of the "risk of interference with medical equipment".

Today – mobile phones and health

What has changed since? Quite a lot. I have picked up some headlines from the last three months. Verizon, three months ago, launched in the US a healthcare business unit, Verizon Connected Health. In this country, both Vodafone and Orange, at the end of last year, announced plans for the healthcare sector. Of course, probably the most positive publicity in the last couple of months for mobile phones and healthcare was from this particular gentleman, who was interviewed by NBC in Miami. He told them that he had used a medical application on his iPhone while stuck under the rubble after the Haiti earthquake to, and the article did not give any more details, "treat his leg injury". In other words, a lot of

positive publicity in the last two or three months about mobile phones and health, quite a transition from just 10 years ago.

Mobile phones and health – What has changed between 2000 and 2010?

What has changed between 2000 and 2010? There have been quite a few studies, for example the report from Professor Sir William Stewart in 2000 and later on, at least two reports from the World Health Organisation, a well-known paper in the British Medical Journal in 2006, all of which showed that there were minimal health risks associated with mobile phone use, although one has to be careful with the developing brain of young children. Mobile phone use should probably be limited when a child is less than 12 years old. Apart from that, these studies stated that there were minimal health risks associated with the use of a mobile phone.

In addition to that, the introduction of GPRS in 2002 has really changed the landscape. GPRS and now, of course 3G, allows two-way, real-time transfer of data – tonight we are talking about medical data – to and from a remote server. Your mobile phone is both the data entry device using the keypad and the data review device using the phone screen. This has really transformed the use of mobile phones, certainly in the healthcare arena, for the reasons I hope to demonstrate in this lecture.

It is fair to say that in 2010 mobile access to the internet is a reality. People are browsing the web as they go home on the train and mobile phones are now seen in many quarters as tools to facilitate the delivery of healthcare, leading to the new term of mHealth.

Definitions (from UK Department of Health)

What does mHealth mean? What I call mHealth is what everybody else hopefully will understand it to be, broadly speaking, based on the definitions which are very helpfully on the Department of Health's website. In the UK there has been quite a lot of support for telemedicine and eHealth. If you go to the Department of Health's website there are various documents in which you will find these definitions.

First of all, eHealth is found at the top level: health services, information and education delivered through the internet, and related technologies. The Department of Health's definition of telemedicine is slightly specialised; it is not what everyone would necessarily understand telemedicine to be. The way the Department of Health describes it is as a remote interaction, usually from one clinician to another. For example, you may have a specialist looking at a mammogram, in the case of breast cancer, and talking to the patient's consultant. Alternatively, a GP may have a dermatology patient with a skin problem, and information about that patient may be relayed back to a remote specialist. There is then

a dialogue between the GP and the remote specialist, trying to understand in depth what the patient's problem might be.

The interpretation of an electrocardiogram (ECG) is more of a rare example than the two I have mentioned to you, but that is the one that is used by the Department of Health at the moment to illustrate its definition of telemedicine: a technology-enabled dialogue between two practitioners, one of whom is a specialist and will be remote from where the patient consultation is taking place.

Telecare is something different: assisted, independent living, providing devices for people who would rather not go into a nursing home. They prefer to remain at home, perhaps on their own, and therefore would like to have some form of protection given to them by technology. Typically, there might be personal alarms, sometimes worn as pendants round the neck, a falls monitor, bed sensors, and movement detectors. Tunstall is a UK company that does quite a lot of work in this arena. The technology may rely on clever processing, for example in learning what movement patterns are typical for a given patient. The discovery of differences in those patterns of daily behaviour may trigger an alert to a remote carer. Telecare is trying to manage the risk associated with independent living.

Definitions (from UK Department of Health) continued.

mHealth is a form of telehealth, which is the delivery of healthcare at a distance using electronic means of communication. The service user here is the patient, who may be measuring their vital signs at home, although there is a subtlety here to which I will draw your attention later on in the lecture. Vital sign data is transmitted via the telehealth monitor to a remote clinician. The data may be collected from a blood pressure cuff, if you are checking your blood pressure, or from an ECG monitor if there is a problem possibly of cardiac origin. The vital signs are collected by "biometric devices" and then transmitted via a telehealth monitor.

The definition I would offer, to be consistent with the Department of Health definitions, is that mHealth is the delivery of healthcare at a distance, enabled by a mobile phone or similar device, (a wireless PDA, for example). If the mobile phone is used with a biometric collection device, such as an ECG monitor or a blood pressure cuff, then mHealth is a form of telehealth.

The biggest impact of mHealth is likely to be in non-acute, long-term conditions, which require regular management. These are chronic conditions for which there are no cures at the moment; therefore the way to "treat" them is to manage them in a way which is properly integrated into the person's life.

Long-term conditions

Why are long-term conditions such a problem? What are long-term conditions in the first instance? The WHO defines long-tem conditions as health problems that require on-going management over a period of years or decades. Long-term conditions are also sometimes called chronic diseases, but in 2006 the Department of Health decided that chronic diseases should be called long-term conditions. I will adopt that language and talk about long-term conditions. There are many publications that still talk about chronic diseases rather than long-term conditions, but I will use the more modern terminology. I will describe conditions such as diabetes, heart disease or a respiratory condition known as Chronic Obstructive Pulmonary Disease (COPD), mostly smokers' disease.

The statistics are pretty frightening; nearly a third of the country has a long-term condition. If you look at the adult population older than 50, it is a lot more than a third; it is more than a half. Of the 17.5 million people in the UK with long-term conditions, approximately 12 million have a condition such as diabetes, hypertension, asthma or COPD. The other five and a half million are mainly people with arthritis and people who suffer from neurological conditions such as depression.

In the States, the figures are even more frightening: 125 million people, with healthcare costs of approximately $6,000 a year per person. That means that the cost of long-term conditions in the US is $1.4 trillion per annum.

Long-term conditions: a 21st century epidemic

Worldwide the number of people with diabetes is going to increase in 2000 from 171 to 336 million in 2030. Perhaps the more frightening statistic is that one in three of the babies born in 2000 in the US will develop diabetes.

In the UK, there are just under three million people, approximately five per cent of the population, with diabetes, but diabetes takes up nearly a tenth of the NHS budget, £10 billion or so per annum spent on diabetes and its complications.

There are also a lot of people suffering from asthma. If you start developing an asthma exacerbation, which turns into an asthma attack, it can cause your death and nearly 200,000 people worldwide die of asthma attacks each year. There are five million people in the UK with asthma, many of them children.

Why are long-term conditions such a problem?

Your GP spends on average four days out of five dealing with people who have long-term conditions. These patients also use up to 60 per cent of the hospital days in the NHS. The reason for that is that many people with diabetes or asthma are not properly controlled.

41 per cent with diabetes are outside the government target for their blood sugar control. As a result of this people with diabetes spend 1.1 million days in hospital each year. There were 80,000 hospital admissions for people experiencing an asthma attack in 2007 – the most recent year for which we have the figures, and yet at least 75 per cent of those admissions could have been avoided if the patients had been managing their asthma properly.

What happens between visits to the Asthma Clinic?

Even someone who turns up to the Asthma Clinic or the Diabetes Clinic in their local Practice twice a year will spend 8,759 hours 15 minutes on their own each year. It is a problem that we know very well as electrical engineers as the Nyquist-Shannon sampling problem. Here is a young person with asthma, a teenager who was using some of our mHealth technology. Here he is recording his asthma symptoms in the patient diary on the phone; here he is recording his use of reliever inhaler. Young people with asthma are often poorly controlled. This plot shows the raw peak flow data, together with the output of a Kalman filter to smooth the data and extract the trend. Even after smoothing, it is very clear at this point that the young person is using his reliever inhaler excessively because his asthma is out of control. He realises that there is a major exacerbation developing because of the visual feedback given to him on the phone screen. Following advice from his GP, he goes on a course of steroids to stabilize his asthma until the next pollen-related exacerbation begins to develop.

The reason why I have shown you these three months of data is to demonstrate the instability of the asthma. The vertical axis on the plot is the peak flow, which is an indicator of the lung function of the person with asthma. You can see the day-to-day variability in lung function. The twice-yearly visit to the GP Practice is not much use: you need to sample the information much more often. This can be achieved if the patient self-monitors their peak flow and symptoms, which then gives them information allowing them to self-manage or self-care. You are solving the undersampling problem by allowing the individual to have daily information about their condition between the twice-yearly visits to the Asthma Clinic in this case, or to the Diabetes Clinic.

The long-term condition pyramid

Kaiser Permanente in the US have developed a long-term condition “pyramid”, a model which has also been adopted by the Department of Health in this country. At the top you have the most complex patients who are managed by a community nurse or a community matron. These patients probably have several co-morbidities, not just diabetes, perhaps diabetes and COPD. They spend a lot of time in hospital and they are the people for whom telecare may be useful.

The levels I want to concentrate on are the level 2 and the level 1 patients in the long-term condition pyramid, those who can manage their condition adequately through self-management (potentially 70 to 80 per cent of people with a long-term condition), whom we can help by providing them with feedback to manage their long-term condition. The key to minimizing the complications of long-term conditions is to enable patients to become more responsible, to self-manage or to self-care.

Medicine requires evidence before any new programmes or interventions can be introduced and the evidence backing the use of disease-specific self-management programmes for conditions like diabetes is very strong. It is well known in the medical community that self-management is at least part of the answer. The problem is how do you move to a programme or technology that can support millions of people as opposed to 10 here and 20 there?

mHealth for long-term conditions

We focused from 2002 onwards on the mobile phone because of its ubiquity. 90 per cent of the UK population today has some form of mobile phone. It allows you to do real-time data entry and review – you get immediate feedback, it helps you to do the right thing at the time you make your measurement. It also allows you to communicate directly with a remote nurse, a telehealth nurse, based on shared data. Both parties have the data and so you get to the nub of any problem very quickly.

As we are using the individual's' own mobile phone, there is no extra hardware, which makes it a financially attractive proposition based on reduction in unplanned hospital admissions.

mHealth for long-term conditions – (Levels 1 and 2)

Here is the mHealth solution for diabetes: an every-day mobile phone and a blood sugar meter, sometimes called a glucometer. You can either type in the reading from the meter into your phone using the key pad or, if you are technology-minded, you can use a Bluetooth cradle which allows you to connect the meter straight to your phone. In either case, the readings are automatically transmitted by the software application running on the phone. Software at a remote server analyses the incoming data. Immediate feedback from a combination of the software on the phone and on the server is made available to the patient. At the same time, the software on the server also gives information to the remote healthcare professionals so that patients are prioritized. For example, the remote nurse can see who she needs to deal with that day when she comes into work. The mHealth solution is a combination of the mobile phone being an interactive tool promoting self-management and of the regular support available from the telehealth nurse. This regular support is provided

every month or every six weeks, except if the patient is prioritized because he or she is going out of control or because no readings have been done for a while, in which case the nurse calls the patient to try and establish what the problem might be.

Mobile phone – the tool to promote self management

Patient diary (disease specific)

For the patient, the tool to promote self-management includes a patient diary with the relevant questions on the handset's screen. If you have diabetes, you need to think about your calorie intake and how much exercise you are going to be doing. You then enter your blood glucose reading in mmols/litre or use Bluetooth to get the data into your phone. You then get some feedback based on your readings, with personalized limits for hypoglycaemia (low blood sugar) and hyperglycaemia (high blood sugar). This display shows the last five days of blood sugar readings on the phone screen. There is also a longer-term form of feedback: histograms of the last 50 to 60 days or shorter periods if there are a lot of blood sugar readings.

Mobile phone – a tool to promote self management

Personalized feedback screens

Personalized feedback screens have limits that can be adjusted for the individual depending on their particular control at the time.

This is an asthma application running on an O2 XDA. It tells you what the local weather is, because respiratory conditions are influenced by the weather. You are provided with the weather and air quality in Newcastle if you are in Newcastle. The screen display also shows a personalized peak flow because you can learn over time what the target peak flows ought to be for each individual with asthma. The peak flow is displayed on a personalized scale, showing how you are doing with respect to your own target value. The asthma application has personalized target values, not just the general guidelines.

Regular support from telehealth nurse

Algorithms for patient prioritisation

In terms of the telehealth nurse, in three clicks on her web page, she can get to the patient that needs help. This is the overall screen, the top-level screen from t+diabetes (the application commercialized by t+ Medical). It shows the clinic for that nurse, a summary of all her patients. All the data I am going to show you is anonymized. This particular "clinic" consists of a set of employees of t+ Medical.

The patients are prioritized. With a second click, the nurse can look on the next web page at the patients who have had recent low blood sugars (hypoglycaemic readings) and then select one of those patients, and review their individual data with a third click. She can

then send the patient a message asking him or her either to contact her or to start a particular form of treatment, depending on what the problem is. Three clicks on the web and the nurse can be in contact with the patient on their phone and talk to them if she needs to.

Evidence based medicine – summary of clinical studies and trials

For any new drug or medical device to be introduced, the medical profession requires evidence. Medicine is not a single word any more, it is three words: evidence based medicine. I am going to show you very briefly some of the clinical studies we have done in diabetes because I don't have the time to go through all the different types of long-term conditions. Our portfolio of evidence for mHealth applied to long-term conditions consists of about 20 clinical studies now, 12 of which have been published in peer-reviewed medical journals: studies relating to asthma, COPD, diabetes, hypertension, cystic fibrosis, chemotherapy and in health economics, published in various journals and at various conferences.

Diabetes Type 1 and Type 2

I want to concentrate on diabetes type 1 and type 2 because I only have time to cover one long-term condition to try and convince you of the advantages of mHealth technology. Type 1 diabetes, often called juvenile onset diabetes is an auto-immune disease usually identified in childhood. It permanently destroys the beta cells in the pancreas and the body can no longer make any insulin. If, as a type 1 diabetic, you don't inject yourself regularly with insulin using an insulin pen, the high sugar levels can cause a coma and then possibly death, through diabetic ketoacidosis.

Type 1 diabetes accounts for about 10 per cent of people with diabetes. The real explosion, in what has sometimes been called the McDonald's generation, is in type 2 diabetes, where, as a result of obesity, the person develops type 2 diabetes. The pancreas is no longer able to meet the body's needs for insulin or the insulin is not used effectively. Usually you start managing type 2 diabetes by diet and exercise; however, it is a deteriorating, chronic disease and gradually diet and exercise are not enough, you have to start taking oral medicines. Eventually that may not be enough either, and you will have to switch to learning in your 50s, 60s or 70s how to inject yourself with an insulin pen – which can be quite a frightening experience at that age.

Diabetes complications

Diabetes is tough because if you don't give yourself sufficient insulin you will have high blood sugar. In the long-term, that causes microvascular (small blood vessel) complications, for example in the eye, leading to diabetic retinopathy. A lot of people with

type 1 diabetes go blind because they do not manage their diabetes properly in their youth. Similarly, microvascular complications in the blood vessels in the kidneys cause many people with diabetes to end up on dialysis. Finally, there can also be microvascular complications in the lower limbs, leading to a leg having to be amputated. Those are the microvascular problems (high blood sugar levels) which require regular insulin injections for their prevention.

However, if you give yourself too much insulin, you can become hypoglycaemic and your low blood sugars can cause you to have dizziness and even get you into a hypoglycaemic coma. People with diabetes are therefore walking a very narrow tightrope between high and low blood sugars; that is why it is very important to help them self-manage and self-care properly.

Even then that is not the end of it, as there are also macrovascular complications: complications of the large blood vessels associated with the high blood pressure which often comes with diabetes and these can lead to coronary heart disease, leading to a coronary heart attack or a stroke.

The complications are rarely fatal but give the patient a very low quality of life for one or two decades or longer. It is very expensive for the NHS to look after these people and the complications which arise out of poorly-managed diabetes. That is one of the reasons why the NHS is spending £10 billion a year managing and treating three million people with diabetes.

Diabetes self management

For people who don't have diabetes, blood sugars should vary from 4 mmols/litre before meals to 8 mmols/litre afterwards, but of course these values fluctuate up and down much more in a person with diabetes. These fluctuations are an indication of the short-term blood sugar control. For an assessment of longer-term control, you have what is called an HbA_{1c} test. It is all to do with the haemoglobin molecule (carried by the red blood cells) to which glucose binds. Red blood cells have a lifetime of approximately 120 days, so your HbA_{1c} level tells you about your blood glucose control over the past four months. For most people in the audience here tonight (i.e. without diabetes), the HbA_{1c} reading would be between 3.5 to 5.5%. For people who have very well controlled diabetes, a value of 6.5% indicates good control. The government target is 7.5%, but 41% of people with diabetes are outside this government target.

Diabetes complications

However, people with diabetes can bring their HbA_{1c} level down by improving the self-management of their condition. For every 1% drop of HbA_{1c}, you reduce the risk of microvascular complications, blindness, dialysis or limb amputation, by 33 to 37 per cent. It is well worth doing.

Oxford Diabetes Type 1 clinical trial

Our first mHealth study was in type 1 diabetes, juvenile onset diabetes: a randomised controlled trial, which is the highest level of evidence you can have in medicine. In such a trial, you have a control group and an intervention group, which allows you to quantify the effectiveness of the intervention.

We identified young people with type 1 diabetes, aged between 18 and 30, who were using insulin therapy which was either twice daily or basal-bolus, giving themselves insulin at night before going to bed and then a bolus before every meal. All of the patients who entered the trial were poorly controlled: their HbA_{1c} value was between 8 and 11%. The trial was designed so as to detect a difference of 0.7% HbA_{1c} at the end of the intervention between the two groups, based on mean values.

Oxford Type 1 diabetes clinical trial

We used the development version of what is now t+ diabetes and the control group was given a mobile phone and a blood glucose meter, with just an electronic patient diary on the phone. The intervention group was given the whole of the t+ diabetes product, including the feedback screens seen earlier, as well as the regular telehealth nurse support.

Results – patient compliance

It is quite interesting to review patient compliance during the trial. On the vertical axis here, we have the number of readings per patient: twenty, for a seven-day week, represents about three readings a day. You can see that those in the intervention group (who had all of the features of the t+ diabetes application plus the regular support from the telehealth nurse) remained compliant throughout the nine-month trial. The patients in the control group were just as good in the first four or five weeks, but then eventually their compliance tailed off. That is very important. mHealth has to deliver technology that keeps people compliant not just during the initial excitement of using a new form of technology, but for life because a chronic or long-term condition is exactly that – for life.

Changes in HbA_{1c} over nine months

The average HbA_{1c} value for both control and intervention groups was 9.2% at the start. We had a decrease in HbA_{1c} of just under 0.7% in the intervention group after nine months, but those in the control group, who also had a mobile phone and an electronic patient diary on their phone, did also improve to a certain extent. As a result, the difference in the end between the intervention and control groups was not as large as we had hoped for, because the control group improved through having access to minimal mHealth technology.

Oxford Type 1 diabetes clinical trial

Summary of results

We did have a statistically significant reduction in the HbA_{1c} level in the intervention group, a difference of 0.62% from the start to the end of the trial. Also, while the number of well-controlled patients in the control group hardly changed at all (from 18% to 25%), in the intervention group it went up by a factor of four (from 11% to 49%). The intervention was cost-effective, as the telehealth nurse spent no more than about 10 minutes, on average, each month talking to each patient in the intervention group, hence very much a cost-effective intervention.

mHealth for the elderly population

Insulin titration in Type 2 diabetes

There is a myth that mobile phone technology might well be appropriate for those between 18 and 30 but it is not appropriate for elderly people. Type 2 diabetes, which affects people in adult life, is growing very fast and, as I have already mentioned, the most difficult transition is for patients when they move from oral medication to insulin injections in later life.

We set up a trial with local GP practices in Oxford where we identified patients with type 2 diabetes. These patients had a mean age of 58; some of them were in their 70s. Their mean body weight was about 100 kgs and their HbA_{1c} levels were over the government target of 7.5%. The mean average use of insulin per day at the start of the study was 48 units, showing that the use of insulin was not hugely effective.

t+ diabetes

Insulin titration in Type 2 diabetes

Fasting BG over time (one patient)

Again, we gave everyone in the observational study a mobile phone. These limits on the slide showing the fasting blood glucose readings indicate the zone of control, from 4 to

10 mmol/litre. Each patient was given two to three weeks at the start of the study to get used to the mobile phone technology.

Then the nurse brought them in and showed them how to use the insulin pen. You can see that, very quickly, the fasting blood sugars start to fall from the red to the amber region, with the occasional green reading. You can see that in just over three months this patient has gone from being completely out of control to being almost perfectly well controlled as a result of the support from the telehealth nurse and the feedback on their phone.

Insulin titration in Type 2 diabetes
Weekly fasting BG averaged across all patients

This slide shows the average for the weekly fasting blood glucose values for all patients during the study from week one to week 26, and you can see the improvement despite the variation from patient to patient over the period of six months.

This study was an integration of telehealth within Primary Care. Patients in their 50s, 60s, or 70s with uncontrolled diabetes, used a standard algorithm for self-titration of insulin, as well as the t+ diabetes application and a telehealth nurse to help. The overall result was a decrease in HbA_{1c} from 9.5% to 8.7% and an insulin increase from 48 units to 63 units. This was a very successful study, the results of which have now been published, reporting also very positive feedback from clinicians, practice nurses and patients. Possibly the most important result was the fact that patients were able to use the equipment apart from five who dropped out. The overwhelming majority of the patients were enthusiastic about the extra support provided by the t+ diabetes application in a difficult period of their life when they were switching to the use of insulin to control their diabetes.

The medical case for mHealth
Evidence based medicine

Medicine is evidence based. We have completed 20 clinical trials in the last six or seven years. Previous trials with asthma patients showed a reduction in uncontrolled use of reliever inhaler and patients reported far fewer symptoms.

The Economic Case for mHealth
Hospital Admission Avoidance

In terms of the economic case, the number of admissions each year for COPD in a group of patients in Bristol was reduced from 1.64 per annum to 0.7 per annum, a 67 per cent reduction. We have also achieved a very significant reduction in systolic blood pressure

in six months in patients following discharge after a minor stroke; that will make a huge difference to the risk of having a major stroke, as raised blood pressure is a major risk factor.

The Economic Case for mHealth

Hospital Admission Avoidance

If you look at the Department of Health's website, you can find three studies from Medway Council, Birmingham and Sheffield Primary Care Trust which have shown that between 48% and 67% of emergency hospital admissions could be avoided through some form of telehealth, not necessarily mHealth. The average between the three studies is a 55% reduction in emergency, or unplanned, admissions.

Let us assume that, when a patient goes into hospital after an unplanned admission, they will spend two days there on average, although very often patients with COPD will stay at least a week if not 10 days. We can also assume that a hospital bed in a typical in-patient ward costs £1,000 per day. Each patient with a long-term condition who has been admitted to hospital will have a Patient at Risk of Re-admission (PARR) score. If we consider 1,000 patients with a long-term condition and a 60 per cent PARR score, this means that in a given year there will be 600 admissions, hence the need to spend £1.2 million looking after these patients in hospital.

If you now introduce a form of mHealth triage service such as t+ diabetes or t+ COPD and assume that you achieve just the average reduction of 55%, 45% of the patients will have an unplanned admission, i.e. 270 patient admissions. Assuming a reduction in unplanned admissions of between 48% and 67%, these admissions will cost between £396,000 and £624,000, with an average of £540,000.

If we concentrate on the average figures, mHealth will generate a saving, on average, of £660,000 per thousand patients. You can see immediately a system that costs less than £660 per patient per annum is going to save money.

A lot of telehealth solutions rely on a £1,000 box installed by someone in a white van and then there are costs of tens of pounds per month per year, which is one of the reasons why perhaps telehealth has not taken off yet.

The Economic Case for mHealth

Hospital Admission Avoidance

Remember with a mobile phone it is the person's own device therefore the sums make much more sense. The saving was £660,000, here the cost charged by t+ Medical is £100 per annum for the software licence for one patient; it comes down to £75 per annum per patient for 1,000 patients. If we work with 1,000 patients, the monitoring service (i.e. the

use of the telehealth nurse) is £12 a month or so (£143 per annum), which means, if you add those two numbers, £75 plus £143, a total cost of £218 per patient, i.e. £218,000 for 1,000 patients, a net cost reduction of £442,000. That is simply because mobile phone technology has no hardware cost, if one is using the person's own mobile phone.

How many people might profit from the use of such technology? There are 152 Primary Care Trusts (PCTs) in England – how many patients per PCT?

Stratification of Patients with LTC
Average of 58,000 asthmatics, diabetics, hypertensives per PCT

Stratification of patients with LTC

If we assume an average of 58,000 people with these long-term conditions (asthma, diabetes and hypertension) in the average PCT, 20% of these could be using mHealth, i.e. 11,600. Remove half a percent of patients who would be using telecare and you have about 11,000 people on average. If only one in five choose a mobile phone to manage their condition, which is a reasonably conservative assumption, then you would have a total "market" of patients of about 1.7 million which would be a cost saving per year for the NHS of about three quarters of a billion pounds: a very strong economic case for mHealth in terms of hospital admissions avoidance, using figures freely available on the Department of Health website.

The Patient case for mHealth

What about the patient case? There are patients who have allowed us to use their data, for example relating to some work which we did with Southampton PCT, with t+ again supplying the technology and the telehealth nurse. This slide refers to a young man diagnosed with type 1 diabetes in his 20s while at Southampton University, who decided to do a sponsored cycle ride for Diabetes UK, from London to Paris. He started riding around Southampton, and kept a blog – that is why we have all this information. He would stop every five or ten miles to measure his blood sugars with a Bluetooth device directly into his mobile phone. Here are the trends, with here a very low value, 2.7 mmol/litre, which is below the hypoglycaemic limit of 4.0 mmol/litre. He writes, 'sugar, sugar' in his diary on the phone, which you can interpret in several different ways. This patient is using the mHealth application to manage his diabetes as he seeks to learn how to do exercise, in this case a sponsored cycle ride.

This slide refers to someone much older, a 69-year old man, with recently diagnosed type 2 diabetes, who ended up in hospital. While in hospital, he stopped taking his insulin but carried on doing his blood sugar readings which shot sky high. Because the t+ telehealth

nurse saw this hyperglycaemic red event, she phoned the patient, advised him immediately to re-start insulin, and checked with the local diabetes clinic which confirmed the advice. This rapid response prevented at the very least a three-day admission, possibly longer, for someone who would have been in a much worse state if they hadn't been using the mHealth technology.

We have lots of testimonials from patients; I have just given you a couple of examples here.

Another application of mHealth

I very briefly want to talk about another application of mHealth, which is often confused with what I have talked about so far and I am keen to try and clear the confusion.

What we are trying to do is to keep people out of hospital as much as possible. Another potential application of mHealth is to enable people to be discharged early from hospital. There you need to monitor vital signs such as the heart rate, oxygen levels, respiratory rate continuously, with blood pressure and temperature measurements made from time to time. The continuous monitoring requires low-power, wearable sensors. If you go to the IET or IEEE Transactions, you will see hundreds of papers on wearable sensors.

Continuous vital sign monitoring in the home

Another example here is from the BBC website, from 2008, showing two home monitoring applications, a bed packed with sensors and a vest with electrodes allowing the continuous measurement of vital signs.

Home monitoring of vital signs

The active vs. passive patient

Lower down on the webpage, Dr Nicholas Robinson, one of the medical advisors to NHS Direct, also a member of the telehealth forum for the Royal Society of Medicine, says that the real challenge of this technology is not making the measurements, but working out what to do with them so that you are not constantly getting false alarms. This type of home monitoring has the potential for generating hundreds of false alerts. The critical distinction between wearable sensors is that patients are *passively* monitored, leading potentially to hundreds of false alerts in a week, whereas a patient who takes a finger prick of their blood sugar or uses a blood pressure monitor, will generate far fewer false alarms as this represents active monitoring initiated by the patient. There is a very important distinction between passive monitoring, which is very hard from the point of view of reliability of data, and active monitoring which is reasonably easy.

Although there are many papers in the literature reporting short pilot studies with a few patients or individuals with wearable sensors in their home, there is no reliable, working solution because it is extremely technically challenging.

Continuous vital sign monitoring

What we have done is to develop technology for the continuous monitoring of vital signs within the hospital context and gradually come down levels of criticality.

We originally developed vital sign data fusion algorithms in acute care. This allows you to drive the number of false alerts right down and we are now gradually moving down from acute care to the general ward. These patients are monitored with wireless sensors; with hospital Wi-Fi and a nurse PDA, that is a workable solution which is nearly usable in the home.

Vital signs monitoring in ambulatory patients

We have developed a finger probe solution based on pulse oximetry, with a battery in a wrist watch to supply power for the Bluetooth transmission of the data to the nurse PDA. Patients walk around with the finger probe, giving the oxygen saturation levels from the light absorption through the finger at two different wavelengths, the pulse rate and the respiratory rate which is estimated through clever signal processing.

The nurse takes the blood pressure and temperature every few hours using a wireless PDA which also receives the information from the sensors via Bluetooth. All of the information is fed back to a central station – where the pulse rate, the respiratory rate, the oxygen saturation, the temperature, the systolic and diastolic blood pressures, are displayed for each patient. In addition, a summary of the patient status for all patients in that ward is available on the central station.

Briefly, the signal processing required to estimate the respiratory rate is based on the observation that the amount of blood transmitted through the finger is modulated in amplitude by breathing. In addition, heart rate is also modulated by breathing. The interval between successive heart beats, even as you sit in a relaxed fashion, is not constant. It slows down during expiration and speeds up again during inspiration. Filtering and cubic spline interpolation of the time series of intervals between heart beats gives a signal which is just like the reference respiratory rate signal shown here. Data fusion using both the repetition rate modulation and the amplitude modulation to identify the candidate poles in an all-pole model of the time series allows the extraction of a relatively accurate respiratory rate.

Continuous vital sign monitoring in the home

We are close to moving the vital sign monitoring technology using the combination of wireless sensors and data fusion software from the hospital to the home. This year, we are starting pilot projects with patients on dialysis and patients who are recovering from cancer surgery, so they can go home early.

mHealth for the developing world

Our expertise in mHealth is not limited just to the developed world, it is also highly applicable to the developing world. As I am sure you know, the number of mobile phone subscriptions is now running close to the number of people on the planet. Interestingly, three quarters of mobile phone users are in the developing world and 80 per cent of the world's population lives within range of a cellular network.

Examples of existing mHealth applications in the developing world (text messaging)

Many mHealth applications have been developed using text messaging in countries like South Africa with tuberculosis or HIV patients and patients needing to attend follow-up clinics. These have been quite successful pilot projects.

"SMS for Life"

Vodafone has been working with a number of partners on a project called SMS for Life which has the aim of managing drug stocks, in this particular case drugs for malaria, which is still a very big problem in sub-Saharan Africa. Making sure that you have the right amount of drugs at the hospital or the health centre where they are dispensed is a hard logistical problem where mobile phone technology can make a huge contribution. This is a successful project for Vodafone and its partners in Tanzania.

Community Health Worker Project

We are also working in South Africa to enable the community health worker, who is the interface between the patient and primary care. These community health workers often are the people who deliver the healthcare in the developing world. We are doing this in partnership with Vodacom, a company in which Vodafone has a majority stake. In this case, the community health worker with the mobile phone technology visits a patient, scans a 2D bar code, and goes through a basic Q&A tree, relating to the service being provided. All of that information is transmitted from the community health worker's mobile phone. The availability of GPS as part of the solution allows the NGO managers, the nurses, the clinic and the Department of Health programme managers to know that the health care is being delivered on the ground.

There is also a long-term condition epidemic in the developing world

There is also a major long-term condition epidemic in the developing world. It might be worse than in the developed world because the obesity problem instead of going through two or three generations in this country for example, sometimes occurs in one generation. People who were brought up and lived on the land as farmers now live in cities and in their 50s and 60s develop type 2 diabetes.

If you look at this diagram showing the problem in the developing world in 1990 and what it will be like in 10 years time, you can see that the long-term condition epidemic is probably worse in the developing world. We are working with people such as Professor Mayosi in Cape Town to try and adapt our existing mobile phone technology, so that it is used appropriately on the ground within the South African healthcare system.

Example of new mHealth application in the developing world

The final project which I shall describe is related to the problem of tuberculous pericarditis. This is when the lining around the heart becomes inflamed, usually because of an infection, and there is a build-up of fluid around the heart. Because of the reduced immunity as a result of the prevalence of HIV in Southern Africa, tuberculous pericarditis is on the increase. It can cause sudden cardiac death; there are sometimes precursor signs such as high heart rate (tachycardia) because there is less stroke volume with every heart beat as a result of the pressure around the heart. Other signs may be an abnormal heart rhythm (atrial fibrillation) or a change in heart sounds. One of the medical applications developed for the iPhone is a digital stethoscope. My colleague Dr Gary Clifford formerly at MIT but now back in Oxford has been using the mobile phone as the “sensor” and the means of transmitting data. As there is a microphone in every mobile phone, you just apply the mobile phone to the chest to measure the heart sounds. From the interval between two consecutive heart sounds, you can derive the heart rate and diagnose tachycardia using the mobile phone application.

What we are trying to do now is to adapt this principle for low-cost mobile phones, not just an iPhone.

From 2002 to 2010, the beginning of mHealth

To conclude, why is mHealth here to stay?

First of all, if we go back 10 years mobile phones were banned in all hospitals. If you go to the John Radcliffe Hospital today, you will see most consultants using iPhones on a daily basis. For that reason, we have loaded the stroke patient questionnaire on the stroke consultants' iPhone. This screen shows the modified Rankin scale score which is usually done at the time of hospital admission, a week later, etc, to see the progression of the stroke.

In terms of the industrial sector, Vodafone and Orange have recently outlined plans for mHealth business units. They have seen that there is a business opportunity in mHealth and other mobile network operators are joining in. This is a very recent development, which has occurred in the last six to 12 months. It is certainly happening in the UK, but also very much in the US.

mHealth – the patient's perspective

What about the patient? Everybody uses mobile phones nowadays. The iPhone apps have generated a huge amount of interest in mHealth in the last couple of years. A recent survey in the US reported that 40 per cent of people would be happy to have mHealth to supplement their care and that nearly 20 per cent would upgrade their current mobile phone plan, switch providers if they had to, to get access to mHealth services.

mHealth – the patient's perspective con't.

However one has to be very careful – the iPhone medical applications are both an opportunity and a threat. We would argue, based on our experience, that the downloading of an insulin calculator onto a mobile phone can lead to *worse* self-management; you can become over-dependent on the device to calculate your insulin dose. We only ever offer decision support with our mHealth technology. You have to understand, based on the information provided as part of the feedback on the mobile phone, which insulin dose to inject. You should never rely on the phone to "make the decision", because the day you forget to recharge it or leave it at home you may give yourself the wrong dose; similarly, if you enter the wrong data, you may give yourself a dose without understanding that it could kill you. iPhone apps such as insulin calculators are potentially quite dangerous.

Nevertheless, in all the studies where we have had patient questionnaires, patients have been very keen to use the technology because they can see the benefits: they get better health outcomes and they get help when they get into difficultly. One other benefit: they don't have to call the telehealth nurse, the nurse will call them and that is also very helpful because sometimes patients don't know if they are hypochondriacs or not – for the nurse to call them is a tremendous help to them.

However for sustained use, the application needs to be personalized and targeted to what the individual needs at the time. For example if you are newly diagnosed, you will use mHealth in a different way to someone who is stable and has had diabetes for many years. Again, if you are changing medication, you will need a different application on your phone, personalized to your context.

mHealth – the HCP's perspective

From the point of view of the healthcare professional, only the applications that have been validated in the clinical context will survive. Clinical trial evidence for mHealth is needed before it can be fully adopted by the medical profession. However, that evidence is growing and healthcare professionals are beginning to understand that these tools allow them to concentrate on the patients that need their help and support. The patients can be prioritized using software tools, which analyse trends and pick out the patients on whom the healthcare professionals need to spend their time. This means that they can be more efficient and concentrate on the patients who need their help – you have a more efficient health service.

mHealth – the health care professional's perspective

The costs of any health service, the NHS in this country, have to be controlled. The principal mechanism for that is to reduce the numbers of emergency visits to the GP Practice or the numbers of unplanned hospital admissions. We have already demonstrated in three or four of our clinical studies that those numbers can come down as a result of the use of mHealth.

mHealth is the most cost effective form of telehealth, because it uses the patient's own mobile phone. The issue of integrating mHealth within the healthcare delivery system is being addressed. Connecting for Health in the UK has recently issued some guidelines showing how to integrate telehealth into the way the NHS delivers patient care.

mHealth in 2010 and beyond

mHealth is here to stay, and it will grow because one key objective of medicine today is to move delivery of healthcare away from the hospitals where it is very expensive and bring it as close as possible to the patient's home.

In the 1950s, every third or fourth bed in a hospital was occupied by someone who was a middle-aged patient with hypertension (high blood pressure). From the 1960s onwards, the treatment of hypertension was moved to the GP's surgery based on blood pressure measurements made in the surgery. Hypertension management is probably the number one success story of preventative medicine, with large reductions in the number of

people who suffer congestive heart failure, strokes or end-stage renal disease, which means having to be put onto dialysis.

However hypertension is still a major problem; it costs $70 billion per annum in the US. Some of the people who have their blood pressure measured in the doctor's office have a lower reading in the doctor's office than the real value during the day – that is called masked hypertension and it affects about 10 per cent of the hypertensive population. What we have developed in Oxford, in a pilot study with a number of GP practices, is moving the detection of hypertension away from the doctor's practice by providing Bluetooth plus mobile phone technology to the patient for self-monitoring of their blood pressure, if the GP thinks they may have masked hypertension. As a result of the simplicity of the mobile phone technology, we have reduced the training to a package that the practice receptionists can give.

The last word should be given to the patients. In our hypertension pilot study, two of the comments which we had from patients were: "1.The system made me feel especially cared for. 2. Now I am happy based on the evidence to accept a diagnosis of hypertension". Thank you very much. [*Applause*]

Professor Michael Walker: Thank you very much, Lionel, for that splendid talk. Now we have a short time for questions. Could I ask you when you ask a question to first of all raise a hand so we can see where you are and then if you could let us have your name and affiliation that would help us a lot. Have we some questions?

Gary Clifford (Oxford University): Lionel – I was looking at your compliance graph for the diabetes and I notice that on the non-control group you had a nice oscillation with a period of about two to four weeks. I was wondering whether that was significant.

Lionel Tarassenko: Yes, it is related to when the telehealth nurse calls the patients. For some people behaviour changes before the nurse calls them because they know the nurse is going to call them and for some people it is after the nurse calls them, but it is roughly every four weeks that the nurse engages with them. You can't just rely on the technology; you need reinforcement from the telehealth nurse. There is oscillation in the compliance and it is not an artefact.

Geoff Lomer (Fellow of the Royal Academy): Fascinating technology and obviously a great future. I was interested in a slightly non-technical question. You made quite a big point about the cost savings realised by avoiding hospital admissions. Thinking about the National Health Service and the highly convoluted structure of finance, is it straightforward to get money saved on hospital admissions somehow into the Primary Care Trust, or is that going to be a huge vested interest situation?

Lionel Tarassenko: There are better qualified people in the audience to answer this question, but no, it is not straightforward at all. What there is, for example, in Oxfordshire is the Healthy Oxfordshire campaign where primary care and secondary care are being pulled together to look at the savings in the round. It is very important for primary care and secondary care to work together because in fact, you are quite right, hospital managers do want their hospitals to be full. If you get £1,000 per day per patient you want a full hospital. The Primary Care Trust, however, wants to minimize the costs that they have to pay the hospital because every time one of their patients ends up in hospital then the costs are meant to be borne by the Primary Care Trust under the Payment by Results scheme. These costs are topics of great debate and different trusts seem to manage better than others.

The NHS is the third biggest employer in the world after the Chinese Army and the Indian Railways: 1.4 million people are working in the NHS. It is quite difficult to solve its problems; it is not just the question of getting a few executives around the table and banging heads together. People are now becoming receptive to the use of technology in making a difference. I could come back here in 10 years and give you an update. We won't have solved all the problems but hopefully we will have made some progress.

Peter van Manen (McLaren Electronic Systems Ltd): Just following on from that argument the compelling economic argument for mHealth is the explosion of long-term conditions. We are going to reach a point where we don't have the hospitals to support that and then it becomes the lower operational cost of mHealth versus a huge capital cost of new hospitals.

Lionel Tarassenko: Yes, that is one of the arguments. At the top level people do understand that. One interesting issue, for example, is how diabetes is being addressed. Diabetes does not generate that many emergency hospital admissions; the cost is to be found 10 or 20 years down the road when people with diabetes have to be put on dialysis or they have had a stroke, for example. The current government in 2000/2001 was

very brave and put a lot of effort into setting up a National Service Framework for diabetes, even though the benefits won't be visible for another 10 or 20 years or perhaps even longer.

Professor Dennis Chan (Brighton and Sussex Medical School): As an employee of the NHS I am one of those happy 1.4 million you referred to earlier. Off the top of my head, I can think of at least 10 applications for mobiles that we should be doing and need to be doing; there is no doubt in my mind that this will be the future. It does fall to me as a clinician to inject a note of caution: there are a couple of points here. First of all one has to be careful that we are not going to introduce a two-tiered system here. There are going to be individuals or patients who do take part in this, who do monitor, who do respond to the use of mobile health. We also know there is a huge number of patients who are patient who are not compliant, regardless of whether or not you give them a mobile phone or a gluco pen or whatever you want to call it; we have known that for a long time, that is not going to change.

The other point is also about the long-term conditions you refer to; in the various examples you had, what was central to all of them was the fact that there was one measurable parameter for each of them, be it blood pressure, blood sugar, respiratory rate or peak flow, whatever you want to call it, whereas a lot of long-term conditions we deal with don't collapse down to one parameter. I am thinking of a lot of neurological conditions, for example. I am a neurologist and dementia is one of the big issues now; rheumatoid arthritis is another. It is harder to capture the data because there aren't just single parameters onto which one can collapse the whole management of that patient's health. Don't get me wrong, I am not for a moment saying that mHealth is not a good thing; it is a fantastic tool, I am just making the point for all of the audience that sometimes we have to be careful when there are no other parameters.

Lionel Tarassenko: Thank you very much for making those points; two very valid points. I didn't talk about neurological patients, those with depression or Alzheimer's, for example. There are some tools available for these patients; for example, the Department of Psychiatry in Oxford as you probably know has developed SMS messaging for people suffering from depression. There are also GPS tools for people suffering from dementia who go AWOL. There are other tools, but you are absolutely right, I focussed on those where there was a biometric measurement available to help the management of a long-term condition.

The other point about a two-tier NHS is quite interesting. We are working in Oxford with the George Institute which has a primary focus on affordable health technology for the

developing world. One argument is that it makes sense to develop affordable technology for the developing world because we will need to bring it back to the developed world at some point. You can't have healthcare costs rising faster than inflation for ever. Affordable, cost-effective solutions are going to be very important and some of this technology will feed back into the developed world.

Not everybody wants to manage their health with their mobile phone and not everybody should be asked or forced to do so. I deliberately chose a figure of 20 per cent when I did the numbers for the economic argument in my talk. We have worked with between eight and 10 Primary Care Trusts, in which we have offered the mHealth solution to patients. The take-up is about 20 per cent: you have to have a compatible phone, you have to be the sort of person willing to use the technology. It is not for everybody, but if we already have an impact on 20 per cent of the population, then we are beginning to make a difference on those huge costs. Thank you for making very valid points.

Sir David Davies (Past President): A fascinating talk. I have just one question; you didn't say a lot about the other end – is the telehealth nurse in the GP surgery? Does the nurse need to work 24 hours, or is it three 8-hour shifts? Is it an additional post to be filled?

Lionel Tarassenko: The reason why a telehealth nurse (in a call centre) is viable is that instead of the community nurse getting in her car and visiting perhaps on a good day between six and eight patients, we reckon that the telehealth nurse can look after two to three hundred patients a day. Her case load may even be 500, because she doesn't need to contact all of them; they are prioritized. It is part of the economic model to shift some of the care away from the GPs who are already overloaded anyway. As I showed in my last slide, the receptionist is the trainer for the masked hypertension solution - a shift away from the GP or the Practice Nurse.

In NHS London, they are going to have 100 polyclinics and it would be ideal to have telehealth nurses in these polyclinics. They could interact with the patients and decide who needs to come in, but the nurse would be in the polyclinic and could be looking after a caseload of several hundred patients. The patients that are prioritized will be phoned by her and if the problem is too difficult to sort out over the phone, the patients can be brought into the polyclinic. That is the model of the future and it is beginning to happen, certainly locally here in London.

Sir David Davies: It would be normal working hours? You wouldn't need a three shift system?

Lionel Tarassenko: It will be normal working hours, however, for certain conditions we support, for example, patients who undergoing chemotherapy and get toxicity from their chemotherapy, that has to be a 24/7 service. Normally it will be normal working hours for long-term conditions.

Professor Ralph Benjamin (Bristol University): You mentioned the problems of false alarms in a self-managed situation. There is always a compromise between false alarms and missed alarms, or at least delayed alarms. If the patient is allowed to be self-managed, by definition he is at a somewhat lower risk and therefore you can observe the symptoms for a longer time and see whether the trend is accelerating or staying steady and so on before you generate the alarm. Hopefully this need not be a prohibitive problem.

Lionel Tarassenko: Yes, except that we were talking about people who monitor their blood glucose, their blood pressure, their peak flows. On average, very broadly, that is once a day, so you have to be very careful in terms of trend. If you are at the beginning of an asthma exacerbation you might wait two or three days before you alert, so in this application there is time to monitor the trend.

With wearable sensors, people have their vital signs monitored *passively* and are connected to some electronics that might generate an alert. There is a lot more information to process in this case and it can be difficult to decide whether the patient's oxygen levels are zero because the patient has stopped breathing or because they have taken the finger probe off. There is a lot of engineering to be done in the passive monitoring application, which is at least an order of magnitude more complex than that of active monitoring. That is why we use data fusion. With several signals, you have information that helps you decide whether it is a real trend or a false alert.

Richard Moon (Oxford BioSignals Medical): Lionel, just because we have this audience here, I couldn't miss the opportunity. You made an excellent presentation, an excellent case for both the technology, the clinical case and the financial case. In order to encapsulate this on a wider scale than the National Health Service, what are your thoughts on how we create the political case in this country?

Lionel Tarassenko: I am having lunch with the Shadow Health Secretary next week. Is that a good enough answer? To be perfectly honest, politicians tend to be reasonably receptive when we interact with them. Through the research councils, through

the Wellcome Trust and through the Department of Health, I have spent a fair amount of time in Whitehall, so there is engagement. The person leading the telecare effort on behalf of the NHS is here tonight, sitting in the front row. Connecting for Health have been extremely supportive. It takes time; mHealth is not 10 years old, so what we have managed to do so far is quite a remarkable achievement for seven or eight years.

The one problem we have is the rotation of key personnel. Initially I went to see the Prime Minister's Health Advisor, Greg Beales, who sent me to the Minister of State for Health, Ben Bradshaw. He was supportive and said, "you must go and see the Director-General of Commissioning for the NHS, Mark Britnell". It took an hour and a quarter to convince him and after that he said, "we have to do this. I used to be Chief Executive of South Central, I will send you to the new Chief Executive of South Central, Jim Easton", whom we went to see. He was very supportive and funded a pilot of mHealth in Southampton PCT. We met all the milestones and all the targets which were set in that pilot and then went back up the chain, but not a single person was in the same post. That is within six months of finishing the pilot.

The Chief Executive of South Central, Jim Easton, had moved on to be the Efficiency Czar now in Whitehall; Mark Britnell has gone off to PwC in Australia, so he is no longer here at all. Ben Bradshaw, who I met with George McGinnis from Connecting for Health in his office, has now gone to be the Minister for Media and Culture, and Andy Burnham from Media and Culture has moved to Health – that is one of the problems, the short term nature of politicians' appointments.

Mr Gundform? (McKinsey and Co): I wanted to come back to the phones you use and the technology; they all seem to be rather conventional, non smart phones. Are they enough or have you found any limitations to this technology that might require you moving onto iPhones/Blackberry or other smart phones?

Lionel Tarassenko: We do it right across the range. All the applications delivered by t+ Medical can run on Blackberries and soon on iPhones. I deliberately use a £50 phone because equality of care is very important to the NHS. iPhone penetration is only two per cent, even in the US at the moment. Yes, we are working with iPhones and I mentioned my colleague Gary Clifford who has done some work with them. In general, we want to deliver a solution that will be accessible to people who have a more standard mobile phone. There is a lot more you can do with an iPhone and it will be very interesting to see what is going to happen in the next five years. Even more interestingly, of the medical applications that have been downloaded by people onto their iPhone, within a month 99 per

cent of people are no longer using them. There is a problem with sustainability; it doesn't mean we won't be using the iPhone, as there are a lot of things you can do in terms of web browsing on the iPhone. mHealth will happen but we want to make sure it is accessible to all, therefore not necessarily just those who own a top-of-the-range smart phone.

Toby Lovern (PA Consulting Group): We have heard a lot about the role of the patients in terms of self-monitoring and self-care. I was wondering how you see these technologies impacting care givers around the patient.

Lionel Tarassenko: The healthcare professional and the nurse?

Toby Lovern: No, the immediate family, the group of people who aren't clinicians around the patients who can offer them support and engage with them.

Lionel Tarassenko: That is quite an interesting question. To be perfectly honest we don't have a huge amount of experience because we are dealing with the lower levels of the long-term condition pyramid. We talked about level 1, self-management, level 2, some disease management, but not case management. When the family becomes involved, it is usually at these upper levels of the pyramid. That is telecare, a slightly different application. I have deliberately focussed on telehealth. Nevertheless we do have some experience. For example, the patient in the second case study which I showed was an elderly patient with diabetes. Interestingly enough, it was his wife who ran the application on the phone. He was 69, found it difficult and it was his wife who got the alert and made sure that her husband didn't have to go in for an emergency admission. There is definitely buy-in, but we don't have a lot of expertise because we are dealing mainly at the lower levels of the pyramid.

The myth about elderly people using mHealth is a very important myth to squash. In fact, the type 2 diabetes people with this technology are more compliant than the kids with Type 1 diabetes who are initially very excited about their new mobile phone. Those patients who are in their 60s or are retired make this part of their routine. Provided we can get from the handset manufacturers phones that are not too fiddly in terms of the keypad, I think there will be a lot of take-up of mHealth within that age group.

Professor Stephen MacMahon (George Institute): Lionel, I wonder if you would like to make a comment about the role of regulatory authorities in determining appropriate uses and indications for mHealth applications.

Lionel Tarassenko: Absolutely. In this country we have NICE, the National Institute for Health and Clinical Excellence, and NICE has just set up a medical devices group, so they will be requiring, just as for drugs, medical devices to have the evidence of efficacy and effectiveness submitted to them. This new group has only just got off the ground in the second half of 2009 and so it is not clear how much of an influence it will have. We have sent both University and t+ Medical evidence to it and it will play an increasingly greater part, especially with these new technologies, when there are more than 1,000 medical applications you can download for your iPhone. The medical devices body which is part of NICE will have an important part to play within the whole NHS organization.

In the US it is slightly different. The FDA keeps a close watch on this, quite rightly, and there was an article last week about the dangers of mHealth forcing people to have their phones approved by the FDA. Certainly one of the manufacturers in the early days of mHealth, a Korean manufacturer, developed a glucometer inside a mobile phone whereby you inserted the test strip on which you put the drop of blood into the top of your mobile phone. When the company took this to the States, the FDA asked for it to be approved because the phone had become a medical advice. You have to be very careful. The way we got round this is that we put a Bluetooth cradle around the blood glucose meter so the phone is separate and only connected by a Bluetooth link, which means the FDA is happy to approve the blood sugar meter as a device and the mobile phone remains a non-medical device. The regulatory bodies are taking a closer look at mHealth, and there are clever engineering solutions like Bluetooth but how far they can take us is an interesting point.

Dr Chris Crockford (McLaren Electronic Systems Ltd): Lionel, you were just talking about the FDA and mobile phones; there are over 4,000 medical and fitness apps you can download for your iPhone or your Android. You have spent a lot of time going through clinically proving the validity of your system and in the light of the CE changes regarding software that is now classified as being for a medical device, how do we protect the consumer and show the consumer that there is this huge range of disparity between apps that you can download and applications that you can run on your phone that interpret your data and give you clinical advice?

Lionel Tarassenko: That is a very good point. People can download an insulin calculator onto their mobile phone. It is very dangerous because the day they leave their phone behind, they don't know what to do. Even worse, you can type in the numbers wrongly. People make a lot of mistakes typing data into phones; that is part of our experience. We run checks in our trials and often ask people to re-enter the data if we are

not sure, for example, temperature in our chemotherapy solution when patients may be developing an infection while undergoing chemotherapy. As a result of a mistake in data entry, the phone could tell you to inject yourself with 30 units of insulin; if you are hypoglycaemic that will kill you. I think that insulin calculators should be banned or have a warning such as 'do not use this technology except under the advice of your doctor'. We have always gone through the healthcare professional, so that we have the buy-in of the healthcare community.

People are now becoming consumers of health and there is a great danger of them buying into mHealth technology without checking with experts. It doesn't mean you shouldn't look on the internet when you are first diagnosed with a particular condition, but in the end you should still go and see your GP or the person who is the expert and take their advice; likewise for any of these applications. In the short term, they should come with a health warning on the applications themselves.

Stuart Mustow: Just a brief comment to start with. I am one of those people who found he had type 2 diabetes and became insulin dependent. Certainly I can understand that a large number of people find that difficult, but in my own case it wasn't and in many respects it has been better than taking tablets, but that is an aside. What I was going to ask was with the amount of information that is essentially personal which is being pushed down your phone, what is the security situation, particularly vis-à-vis people who might be out there wanting to know about the health of prospective employees, etc?

Lionel Tarassenko: Thank you for the question. You are the exception that proves the rule, probably because your scientific background allowed you to understand insulin in the context of carbohydrate management, diet and exercise. A lot of people really do struggle, but obviously that is not the case with people who are able to understand all the parameters that are making a difference to the level of blood sugar in their body.

Regarding the second part of the question, I will refer you to t+ Medical who run all these systems. All the medical data is encrypted using 256-bit encryption and stored on servers which have the same level of protection that the MOD and the Financial Services Industry use. It is not different from making a transfer on a bank account using the internet. The company t+ Medical has made sure that the data is protected, encrypted and there has never been – it has been seven years since t+ Medical was started – as far as we know, any successful attack from persons unauthorized to look at confidential medical data.

George MacGinnis (Connecting for Health): I am just going to reflect that when I was a student at the other place, nearly 30 years ago, I was tutored by a materials scientist who wasn't allowed to lecture medical students because he wasn't a doctor or he wasn't allowed to take a fee for lecturing medical students. What a long way things have come. It struck me that one of the issues that I encounter is a clash of cultures. You have described medical trials involving essentially information providing a regulatory regime around chemical therapies, avoiding incidents like Thalidomide. To what extent do you find the medical profession isn't culturally ready for the scale and the speed of the innovation that mHealth represents?

Lionel Tarassenko: In certain pockets of excellence, surprisingly ready. Professor Delpy who is also a Biomedical Engineer, whom I know from my time as a student at Oxford, was one of the first leading guys in biomedical engineering and is now Chief Executive of EPSRC. I would say that biomedical engineering, or medical technology, has undergone a complete change in one generation. It has been 25 years since I finished my doctorate, and in the last clinical study which I did at the John Radcliffe Hospital for my doctorate there was a list of who was going to do what from the top downwards. At the bottom, it said, 'L Tarassenko: knob twiddler'. That was 25 years ago. Now there is absolutely no obstacle. There are people here from the NHS in Oxford and we are equal partners, they are willing to engage.

The biggest difference I would say is due to medical imaging that has transformed the way medics do their business. Medical imaging was developed by engineers and physicists, two of whom from this country won the Nobel Prize for Medicine: Sir Godfrey Hounsfield and Sir Peter Mansfield. It means now that engineers are equal partners. In our Institute of Biomedical Engineering, as the director of the Institute, I have the same place as the other five directors in the building, who direct two Cancer Institutes, the Jenner Vaccine Institute and the Department of Clinical Pharmacology. There is a sea change in the way that engineers are perceived by the medical profession. New technology such as the iPhone is helping our cause. The stroke consultants absolutely love the application we have developed for them. Part of the problem now is dealing with all the things they are asking us to do because they appreciate the power of the technology. A complete sea change from 25 years ago – obviously Oxford may not be typical of the whole country up and down, but mHealth is going to be happening in the next decade. We can be thankful that medical technologies such as MRI and CT, developed by engineers and physicists, have revolutionised the way that medics treat patients.

Professor Michael Walker: Before I invite you to that glass of wine that Lionel mentioned can I thank you all for your questions? This is a very important part of the session and can I especially thank Lionel for a superb lecture and for a fantastic response to all the questions? Thank you very much. [*Applause*]