Future Health

The Future of Health Care: deep data, smart sensors, virtual patients and the Internet-of-Humans

White Paper

11th May 2016

Every day European Union (EU) member states collectively spend close to €4 billion on health care

By 2025 more than 20% of Europeans will be 65 or older, with many in ill health and dependent on the work of others.

We are standing at an inflection point, with technological progress in a number of areas generating new ideas to solve one of the biggest challenges in our lives today – providing sustainable health care to a rapidly ageing population. The current challenge is harnessing this progress for the benefit of Europe's 500 million citizens.

The **Future Health** Community is asking the European Commission for support through a large-scale FETFlagship initiative to stimulate a paradigm change in health care by exploiting the most advanced **sensing, computing and communication technologies to enable personalised and preventative medicine in the framework of the Internet-of Humans.**

Support for **Future Health** will enable Europe to extend and increase its scientific excellence and competitiveness, driven forward by the creation of a cost-effective, sustainable, equitable and truly personalised pan- European heath care system.

Grand Challenge

Our individual existence and well-being depend primarily on remaining healthy and during ill health, receiving the individualised, optimal therapy. The continuing 'health' of our societies is, in contrast, increasingly threatened by the enormous cost of providing appropriate healthcare (currently 4 billion euros PER DAY in Europe alone) in the rapidly ageing societies of Europe. When faced with similar challenges with harmful and/or expensive consequences in other areas we have followed a very simple principle: mistakes are unavoidable in dealing with highly complex processes. While we cannot avoid making these mistakes, we can avoid most or all of their consequences by making these mistakes in silico. This change of strategy has been implemented in most areas of our existence, increasing efficiency, saving lives and reducing costs.

This enormous progress has, as yet, reached neither our health care system nor the way we develop new drugs. Drug based therapy and prevention is still statistical, with many patients receiving drugs, which are ineffective or, even worse, harmful. Unavoidable errors in drug development still cause the cost per drug reaching the market to remain in the multi-billion euro range and endanger patients participating in large, non-stratified clinical trials. In addition, our 'health' care system is still far too much a 'disease' care system. The majority of our efforts are focused on treating rather than preventing diseases; or at least diagnosing diseases (or their progression) early enough to be able to react.

Changing this will require nothing less than a revolution, based on technical developments, but intimately linked to many other aspects of the organisation of health care and its legal and regulatory basis (see also www.healthcarecompacteurope.eu).

Game Changer

We propose a vision of a truly individualised health care and disease prevention system in Europe, based on a detailed characterisation (e.g. clinical, molecular, imaging and sensor based) of the patient/individual and their wellness, health and disease course. A vision that is related to a paradigm change in healthcare by exploiting the most advanced sensing, computing and communication technologies to enable personalised and preventive medicine in the frame work of the Internet-of-Humans (IOH).

Future Health objectives:

- To develop the technology, the required infrastructure, and the legal, regulatory and educational environment for a fully sustainable health care system that will offer truly personalised medicine, prevention and wellness for European citizens, providing a completely new Quality-of-Life.

- To develop novel –omics, imaging and multi-level advanced smart sensor technologies and big data/deep data analytics for problem solving in IoH.

- To revolutionize personalized and preventive medicine by unique technology-model-simulation interactions.

- To address the full value chain of the virtual human at all multidisciplinary levels required, from –omics, imaging and sensor data to complex simulation models.

Medicine and prevention have historically been statistical, treating individuals as members of (usually quite heterogeneous) groups. To switch focus from the statistically best therapy for billions to the individual, will ultimately require much more information on EVERY patient, than we had on the whole of human biology just a short time ago. We go from bytes to terabytes, from handwritten notes to a deep -omics characterisation, from a cursory check at irregular doctor visits to continuous monitoring of all relevant parameters throughout life. Our vision is a game changer, of a future in which no patient will ever again receive harmful therapies, flagged by observing negative effects first on the *in silico* model of the individual patient. This will:

- Directly address the enormous (and almost certainly irreducible) complexity of the biological differences between every patient and every disease by deep clinical, molecular and imaging analyses.

- Provide a new generation of frictionless autonomous smart sensors at all levels required by health care data collection: implantable, wearable, environmental. Develop new feedback-interfaces for life-style feedback loops and related diseases.

- Develop computer models of every patient and disease state that allow physicians to test the consequences of all possible therapies/preventative and life style measures in a virtual rather than the real patient, computational 'Guardian Angels' potentially guarding every European from before birth into old age.

- Acquire, store and redistribute the ever-accumulating amounts of data per patient required to fulfil this goal, within a strong governance framework which protects personal data from misuse and ensures privacy.

Scientific Developments

To achieve its objectives, Future Health will develop:

- Clinical/imaging/molecular survey techniques (genome, epigenome, transcriptome, proteome, metabolome, immune status etc.) to provide a detailed characterisation of individuals in health and disease.

- New self-powered families of revolutionary sensors for IoH/truly personalised health care based on energy efficient approaches and heterogeneous integration solutions in bio-compatible form factors to extend human senses and to support specific prevention strategies.

- Self-learning mechanistic/machine learning models translating this information into predictions on the future development of diseases (prevention) and the likely response to specific therapies and preventive measures.

- Data security and availability: hardware to software solutions specific for IoH/personalised medicine data. New human-machine interfaces for IoH/personalised medicine, personalised and capable of non-verbal interactions.

We need to know much more about the patient (or the potential patient), based on advanced -omics (e.g. genomics, proteomics, metabolomics) analyses, imaging techniques, and information from sensors deployed in various form factors. We will draw primarily on concepts developed under two separate Flagship proposals (both of which had reached the final stage of the last competition): IT Future of Medicine (ITFoM: www.itfom.eu), with a very strong -omics component, and 'Guardian Angels for a Smarter Life' (www.ga-project.eu/), with a particular focus on the development of novel autonomous

sensors/low energy computing. In addition, we plan to incorporate a similarly strong imaging component, from the level of individual cells up to the entire organism.

Data is however not everything. We also need concepts to integrate this information and to predict the effects and side effects of possible therapies (or preventive measures) on every individual. Towards this we will build on the concept of the 'virtual patient/virtual individual', proposed in ITFoM. Such a 'virtual twin', updated intermittently by medical/omics/imaging information, and essentially continuously by a multitude of sensors could, in theory, accompany every European through life as a true 'Guardian Angel'. These 'Guardian Angel' models will, to a large extent, be based on modelling the biology of every patient and the diseases mechanistically, providing by far the best chance to translate complex data sets into accurate predictions, complemented by machine learning/statistical techniques, whenever mechanistic models cannot be established due to insufficient knowledge, e.g. on disease mechanisms. Development in these areas will however also help to accelerate and de-risk the development of new drugs, based e.g. on virtual 'clinical trials', starting shortly after (and maybe even before) the synthesis of new candidate compounds, in a 'virtualisation' of drug development matching the enormous positive effects that a similar virtualisation has had on e.g. the car industry.

Technology is only a part of the solution. We will, in addition, have to reconsider many aspects of our health care system, its legal basis, regulations and reimbursement mechanisms, to draw maximal benefits from the significant progress in technologies allowing us to truly personalise medicine and prevention. We propose a vision of a truly individualised health care and disease prevention system in Europe, based on a detailed characterisation (e.g. clinical, molecular, imaging and sensor based) of the patient/individual and their wellness, health and disease course, exploiting the most advanced molecular, imaging, sensing, computing and communication technologies, through an internet-of-humans, for truly personalised and preventive medicine.

Benefits for:

EU citizens, through a radical improvement of their health care (up to 50% improvement in treating serious diseases, halving the negative side effects of today´s generic medicine methods) and through a new quality of life, in which preventive medicine could induce a long-term paradigm change.

European economy, through new job and employment opportunities. Formation of a new vibrant economic ecosystem bridging traditional engineering, computer sciences and health care, with unique opportunities for production in Europe. Reductions in sick leave and health related early retirement; the development of a new European high-tech industry uniting health care and IT will also be catalysed, providing a platform to exploit key technological advances and commercial opportunities that will stimulate the growth and development of regional economies. Although difficult to quantify completely, we can expect long-term economic benefits many orders of magnitude higher than the anticipated costs of the proposed concept. (Even a 1% saving of healthcare costs in Europa alone would, over a ten year period, generate savings of 140 billion)

European industry, particularly related to the goals of having, within Europe, the highly added value production facilities on smart sensors and smart systems, vital for the medical and automotive industries (as per the concepts of Smart Health, Smart Production, Smart Society proposed by ECSEL - http://www.ecsel-ju.eu/web/index.php but taken in our flagship in a much longer term perspective and in an approach that is beyond the one of a bottom-up technology enabler). In this field we expect a strong emergence of startups and creation of a new ecosystem of industries with high innovation content, aiming at supporting new services for a Quality-of-Life in Europe.

Public finances, by curbing the uncontrolled increase in health care spending (potential savings of hundreds of billions of euros). Under our current model of personnel intensive, statistics driven health care, costs will inherently continue to rise in tandem with our ageing societies, leading sooner or later to some form of health care rationing. In contrast, data and computational model driven health care will continue to become more cost effective, driven by significant progress

in computational and analytical techniques, and an exponentially increasing information base flowing back into an evolving, self-learning system.

"One in three people in the Western world develop cancer and one in five die of the disease"

(The Wellcome Trust, UK)

"Cancer deaths worldwide are projected to continue rising, with an estimated 12 million deaths in 2030"

(National Cancer Institute, USA)

Next Steps

We have devised a 10 year plan that has ambitious but practical goals, which will be addressed in a series of 'working prototypes' until final rollout of a system ready to be implemented for multiple disease areas on large scale in European health care. The effort is well balanced between: (i) deep -omics and imaging technologies, data analysis (ii) smart sensing technologies, energy efficient computing, big data analytics for IoH, (iii) data integration, virtual patient models and (iv) personalised medicine validations and field trials.

There are four major phases for development:

Phase I: Initiation.

Initial infrastructure development, development of improved pipelines for omics and imaging data integration in virtual patient models, implantable or wearable sensor solutions, pilot projects in oncology and life-style related diseases (e.g. Type II Diabetes).

Phase II: Expansion and Consolidation.

Development of virtual patient/virtual individual models for the vast majority of multi-factorial, non-infectious diseases, integrating -omics, imaging and sensor data.

Phase III: Maturation and Innovation penetration.

Scale out and clinical engagement across Europe by full adoption of the new methods and innovation by technology-health care interactions, -omics and all-scale imaging and sensing technologies, model validation and model improvements through feedback of treatment results.

Phase IV: Full Implementation of paradigm shifts.

Establishment and deployment in practicing health care systems, effect and impact of personalised and preventive medicine quantifiable.

Collaborators and Support

The idea and the related goals of this proposal find support in previous FET Flagship initiatives: 'ITFoM: IT Future of Medicine', led by Prof. Hans Lehrach (Max Planck Institute for Molecular Genetics, Berlin), and 'Guardian Angels for Smarter Life', led by Prof. Adrian Ionescu (Ecole Polytechnique Fédérale de Lausanne). The technological roadmaps and the networks of partners generated by these two pilot flagship projects create a unique opportunity for implementing a joint concept proposed here. In this way partners from medicine, science and engineering, industry, finance, health care funders, patient organisations, regulators, administrators and the general public will join to develop a stepwise, global, coherent and integrated path towards truly personalised medicine and prevention in Europe (and beyond).

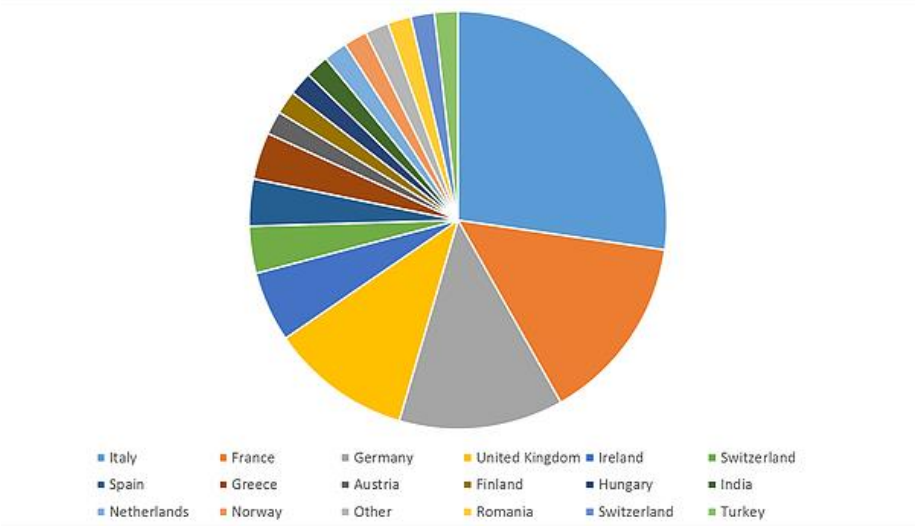
Key supporters:

- CEA, France: Nora Benhabiles, Professor. Director, External Collaborations and Industrial Partnerships at CEA.
- Consorzio Interuniversitario Risonanze Magnetiche di Metallo Proteine (CIRMMP), Italy: Claudio Luchinat, Professor of Chemistry.
- ETH Zürich, Switzerland: Christofer Hierold, Professor, Chair in Micro and Nanosystems, Lothar Thiele, Professor, Chair Computer Engineering and Networks.
- Medical University Graz, Austria: Kurt Zatloukal, Professor of Pathology.
- University College London, UK: Stefan Beck, Professor of Medical Genomics.
- Kings College London, UK: Tony Ng, Richard Dimbleby Professor of Cancer Research, King's College London and Professor of Molecular Oncology at UCL-Cancer Institute, University College London.
- Infineon Technologies AG Munich, Germany: Knut Hufeld, Director, Research & Development Funding, Infineon Technologies AG; Reinhard Pufall, Dr.
- Centre of Systems Biology (SYSBIO), Italy: Lilia Alberghina, Professor, Director.

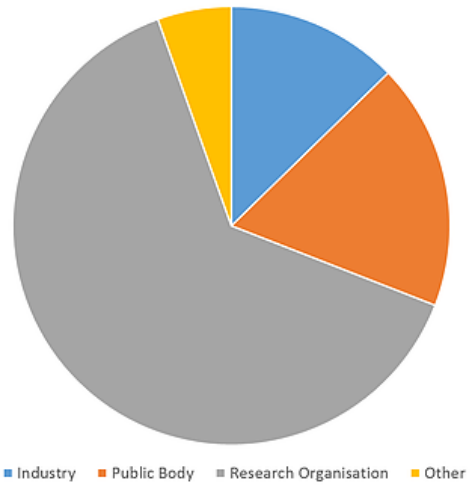
- CEA-LETI, Grenoble, France: Marie-Noelle Semeria, Director; Thomas Ernst, Chief Scientist.
- Fraunhofer Research Institution for Microsystems and Solid State Technologies, Germany: Peter Ramm, Head of Department Heterogeneous System Integration.
- Charité, University Medicine Berlin, Germany: Antonia Joussen, Professor of Ophthalmology. *Chair,* Department of Ophthalmology.
- Maastricht University, Netherlands: Angela Brand, Founding Director, Professor, Institute for Public Health Genomics (IPHG).
- IMEC, Leuven, Belgium and IMEC-NL, Eindhoven, the Netherlands: Chris Van Hoof, Program Director Wearable Healthcare, Professor KULeuven, Leuven, Belgium.
- Università di Bologna, Italy: Enrico Sangiorgi, Vice Rector, Professor, Giorgio Baccaranni, Professor, Luca Selmi, Professor.
- Sinano Institute and IMEP-Grenoble INP - IMEP-Grenoble, France: Francis Balestra, Director of research NRS.
- SINTEF, Norway: Maaike M Visser Taklo, Chief Scientist.
- IBM Zurich, Switzerland: Heike Riel, Director Physical Sciences IBM.
- Intel Corporation, Ireland: Charlie Sheridan, Director, Internet of Things (IoT) research Lab at Intel Corporation
- Science for Life Laboratory, Stockholm, Uppsala, Sweden, Olli Kallioniemi, Director
- INSERM, France: Georges Dagher, Infrastructure Biobanques, Director
- Institut ROCHE, France: Patrice Denefle, Head of Institute
- UCL Institute of Neurology, UK: Xavier Golay, Professor, MR Neurophysics and Translational NeuroscienceHead, Department of Brain Repair and Rehabilitation
- University College Dublin, Ireland: Walter Koch, Professor, Director of Systems Biology Ireland
- Centro Nacional de Analisis Genomico (CNAG-CRG), Spain: Ivo Gut, Professor, Director
- CEA-CNG (Centre National de Génotypage), France: Jean-François Deleuze, Director
- Acabidem University, Turkey: Ugur Sezermen, Professor
- Uppsala University, Sweden: Ulf Landegren, Professor

- **Tyndall National Institute, Ireland:** Dr. Alan Mathewson, Deputy Head - Circuits and Systems & Dr. Kieran Drain, CEO of Tyndall National Institute.
- **KTH, Royal Institute of Technology, Sweden:** Prof. Mikael Östling
- **European Alliance for Personalised Medicine, Brussels:** Denis Horgan, Executive Director

Countries



Institution Type



Contact:

Prof. Hans Lehrach

Max Planck Institute for Molecular Genetics, Berlin, Germany

lehrach@molgen.mpg.de

Prof. Adrian Ionescu

École polytechnique fédérale de Lausanne EPFL

adrian.ionescu@epfl.ch

Future Health