Bertalan Meskó, MD, PhD
*Medical Futurist*

# THE GUIDE TO THE FUTURE OF MEDICINE

BRINGING DISRUPTIVE TECHNOLOGIES TO MEDICINE & HEALTHCARE

medicalfuturist.com

# TABLE OF CONTENTS



# INTRODUCTION

Being a medical futurist means I work on bringing disruptive technologies to medicine & healthcare; assisting medical professionals and students in using these in an efficient and secure way; and educating e-patients about how to become equal partners with their caregivers.

As online platforms and digital technologies change and emerge really fast, we need partnership in healthcare between patients and healthcare professionals; as well as a guide to prepare properly in time for the future technologies which will have to be implemented quickly in everyday practices and in the health management of patients.

Based on what we see in other industries, this is going to be an exploding series of changes and while redesigning healthcare takes a lot of time and efforts, the best we can do is to prepare all stakeholders for what is coming next.

Updated versions of this guide will be published based on your feedback. Please use the Twitter hashtag #MedicalFuture.

I hope you will find the guide useful in your work or in preparing your company and colleagues for the future of medicine.

Bertalan Mesko, MD, PhD
berci@medicalfuturist.com

*Medical Futurist* / *geek medical doctor* / *geneticist* / *speaker* / *founder of Webicina.com* / *blogger* / *university lecturer* / *author*

# DESCRIPTION OF INFOGRAPHIC

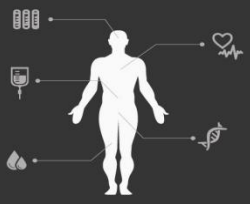
The basic idea was to add 3 perspectives to one infographic featuring the main trends that shape the future of medicine:

1. Which stage of the delivery of healthcare and the practice of medicine is affected by that (Prevent & Prepare; Data Input & Diagnostics; Therapy & Follow-up; and Outcomes & Consequences);
2. Whether it affects patients or healthcare professionals;
3. The practicability of it (already available – green boxes; in progress – orange boxes; and still needs time – red boxes)

The infographic represents the way I see the development of key trends and innovations in the process of delivering healthcare. Some elements could certainly be added to other parts as well, although I chose the points with the most potential.

Examples or summaries from the industry and relevant start-ups are listed next to each trend or innovation.

Click here to see the infographic in the original size.



# THE GUIDE TO THE FUTURE OF MEDICINE

By Bertalan Mesko, MD, PhD

Medicalfuturist.com

| | HEALTHCARE PROFESSIONALS | PATIENTS |
|---|---|---|
| PREPARE & PREVENT | Digital Literacy In Medical Education<br>Virtual Dissection<br>Full Physiological Simulation<br>Curated Online Information<br>Microchips Modeling Clinical Trials<br>DIY Biotechnology | Gamification Based Wellness |
| DATA INPUT & DIAGNOSTICS | Holographic Data Input<br>Medical Tricorder<br>Smartwatch<br>Augmented Reality<br>Real-Time Diagnostics in the OR<br>Robotic Nurse Assistant<br>Semantic Health Records<br>Personalized Genomics | Home Diagnostics<br>Wearable E-skins<br>Embedded Sensors<br>Digestible Sensors |
| THERAPY & FOLLOW UP | Multi-functional Radiology<br>Remote Touch<br>Evidence-based Mobile Health<br>Robotic Interventions<br>Optogenetics<br>3D Printed Biomaterials And Drugs<br>Telemedicine<br>Inter-disciplinary Therapies<br>Virtual Trials<br>Customized Mobile Apps<br>Meaningful Use Of Social Media | Artificial Organs<br>Adherence Control<br>Humanoid Robots<br>Augmenting Human Capabilities<br>Nanorobots In Blood |
| OUTCOME & CONSEQUENCES | Virtual Reality Applications<br>Artificial Intelligence In Medical Decision Support | Redesigned Hospital Experience<br>Recreational Cyborgs<br>Virtual-digital Brains |

Already Available

In Progress

Still Needs Time

# DESCRIPTION OF TRENDS

## 3D Printed Biomaterials and Drugs

More and more objects can be printed with 3D printers and the biotechnology industry is keeping an eye on the potentials of this opportunity. Printing medical devices in underdeveloped areas, printing living tissues, then cells or drugs might not be far from the everyday use. It will re-structure the whole pharmaceutical industry and the world of biotechnology, but regulation will be a huge challenge as anyone will be able to print drugs containing patented molecules at home. Bionic ears and simpler organs will be printed at the patient's bedside while printing transplantable human organs could eradicate waiting lists. Current technological issues such as the lack of available models and blueprints will be solved through crowdsourced and open access databases from communities of designers.

## Adherence Control

Adherence and compliance represent crucial issues in improving the patients' health and decreasing the cost of delivering healthcare. Several start-ups have targeted this issue with different solutions such as the pill bottle that glows blue when a medication should be taken and red when a dose is missed alerting family members about it. In another example, tiny digestible sensors can be placed in pills and transmit pill digestion data to physicians and family members. In the future, it is going to be extremely difficult not to fully comply with the prescribed therapy. Moreover, compliance with medication should be as simple and comfortable for patients as possible.

# DESCRIPTION OF TRENDS

## Artificial Intelligence in Medical Decision Support

The knowledge of even the most acclaimed professors cannot compete with cognitive computers and as the amount of information is exponentially growing, the use of such computing solutions in assisting medical decision making is imminent. While a physician can keep a few papers in mind, maybe a few dozens of papers with digital solutions, IBM's supercomputer named Watson can process over 200 million pages in seconds. This is why Watson has been tested in oncology centers to see whether it could be used in the decision making process of doctors regarding cancer treatments. Watson does not answer medical questions, but based on the input data, it comes up with the most relevant and potential outcomes, and the doctor has the final call. It can only facilitate the work of physicians, not replace them.

## Artificial Organs

An artificial organ is a device or biomaterial that is implanted into the body to replace a natural organ or its function. 3D printing is not the only solution for creating body parts and artificial organs as such organs can also be grown in labs. Surgeons have been able to implant artificial skin, cartilage, synthetic windpipes and artificial blood vessels. In the near future, we will be able not only to replace the functionality of our organs with biomaterials and synthetic devices, but to grow organs which can replace a non-functioning natural organ in its full physiological capacity. Artificial organs could also be used for other tasks such as conserving water. Although probably, a certain number of such organs would be used for cosmetic purposes instead of life support.

# DESCRIPTION OF TRENDS

## Augmented Reality

Augmented reality is a live view of a real-world environment augmented by computer-generated input such as sound, video, graphics or GPS data. Getting information from the internet by wearing a Google Glass or digital contact lenses would be a huge addition to the process of practicing medicine. Operations have already been streamed live from the surgeon's perspective; but it could also display the patient's electronic medical records real-time; or organize live consultations with colleagues. IBM Watson would look for potential errors in the recorded operations. It could also be used in emergency situations as while you are performing CPR, it calls the ambulance to your GPS location. Google Glass can be controlled through voice and hand gestures; while the contact lenses will be controlled with brain waves as there are developments in this area. The whole potential of leveraging the power of augmented reality is huge, although medical professionals should deal with patient privacy and put evidence behind using it in practice.

## Augmenting Human Capabilities

Medical research is meant to discover and develop methods to replace non-functioning organs, capabilities or restore certain functions in the human body. But with the rapid advances of research, instead of only replacing functions, it would be possible to add to our current capabilities and create „super powers". We could decide what to dream about, how to metabolize drugs, how to digest different types of food; to increase brain function or improve our strength through powered exoskeletons.

# DESCRIPTION OF TRENDS

## Curated Online Information

In the near future, whether it is the right and reliable medical information, dynamic resources or medical records online; everything will simply be available to everyone which would purely be the most important development in the history of medicine. As people have to deal with false or unreliable information and resources, curating these with medical professionals and expert patients is the key.

## Customized Mobile Apps

The number of medical mobile applications has been rising for years, therefore patients and doctors find it harder and harder to choose the right app for their health management or work. Customized mobile apps such as the pApp that lets doctors create mobile apps for their patients could be the next step. The functions the app should have such as logging blood pressure or medications can be chosen from a menu; and the patient can download the app right away.

## Digestible Sensors

It is possible to swallow digital devices and tiny sensors for gathering and storing data, transmitting body temperature, heart and respiration rate to an external device. In diseases related to our gastrointestinal system, it could give instant diagnosis by combining the results of lab markers and colonoscopy only by swallowing the device that includes a video camera as well. Examples include Proteus Digital Health, Sano and Equivital.

# DESCRIPTION OF TRENDS

## Digital Literacy in Medical Education

The only way to prepare healthcare professionals for the digital technologies coming to medicine is to include digital literacy and the main trends of the future of medicine in the official medical curriculum. The Social MEDia Course at Semmelweis University has been teaching medical students about the use of social media and even mobile applications. Medical students can access the materials in a gamification based e-learning platform, and answer questions about the topics covered in the lectures on a Facebook page for bonus points. A new course, Disruptive Technologies in Medicine, aims at introducing students to the technologies from genomics to telemedicine they will use by the time they start practicing medicine. Such courses should be available in every medical school worldwide.

## DIY Biotechnology

The methods and materials of biotechnology have been becoming more available to anyone interested in them in the past couple of years. Expensive laboratory equipment is not so much needed for performing biological experiments; elements of the experiments can be ordered on demand and the data or information required are much more accessible than before. The iGem events made it absolutely clear that the number of opportunities in using biotech for different purposes is almost infinite. Biotechnology, especially its DIY division, is the new IT industry. The new generation of scientists represented by Jack Andraka leverages the power of already available resources and materials in order to come up with real innovations.

# DESCRIPTION OF TRENDS

## Embedded Sensors

As an addition to digestable and wearable sensors, tooth-embedded sensors can recognize jaw movements, coughing, speaking and even smoking. Imagine the same wireless technology used in organs providing real-time data from artificial pancreas to recording EEG (electroencephalography) constantly.

## Evidence-based Mobile Health

The number of medical mobile applications has been rising for years, although persuading users to keep on using the apps is a real challenge. The question is not whether such applications could be used in the process of practicing medicine or delivering healthcare, but which ones and to what extent can be useful, therefore evidence based background is needed for implementing mobile apps in the clinical settings. The FDA finally issued a guidance which might facilitate the process.

## Full Physiological Simulation

What if it is possible to examine the human body with all its physiological functions without experimenting with people? One of the most potential applications being developed in this area is the Virtual Physiological Human, a framework enabling collaborative investigation of the human body. Medical students would be able to study the human body in details like never before understanding the core concepts of how our body works and the pathology of diseases. Another example, HumMod consists of 5000 variables describing cardiovascular and metabolic physiology, among others.

# DESCRIPTION OF TRENDS

## Gamification Based Wellness

Gamification seems to be the key in persuading people to live a healthy lifestyle or stick to the therapy they have been prescribed to as 63% of American adults agree that making everyday activities more like a game would make them more fun and rewarding. Such wearable gadgets, online services, games or mobile health solutions can lead to better results if gamification with the right design is included. Improving our health or making our job more efficient can and therefore should be fun. Examples include Shine, FitBit and Lumosity.

## Holographic Data Input

While better data input solutions arise, hardware will probably not even be needed to add data as screens and keyboards will be projected on the wall or on the table making it simple and accessible everywhere in the clinical settings. Holographic keyboards will make us forget about smartphones and tablets, while the data will be stored only in the cloud.

## Home Diagnostics

Patients have been able to measure blood pressure, today they can measure ECG, tomorrow they will sequence genomes at home. Plenty of laboratory methods and procedures will be available at home which could also mean the detection of diseases at an early stage making intervention simpler and more effective. Patients will bring the data to the doctor on any device they use therefore a new role of digital health data analyst will appear soon. Examples include OnStar, Nanobiosysm and AliveCor.

# DESCRIPTION OF TRENDS

## Humanoid Robots

Robots built to resemble the shape of the human body might soon play a role in our lives. Due to the shortage of caregivers worldwide, humanoid robots could be able to provide basic care or company for patients. Developments from DARPA such as Atlas, the 188 cm-tall humanoid robot or the robotic AlphaDog show the amazing potentials and the rapid advances in this area. In a few years' time, not only these robots will assist patients worldwide, but we will be able to print them in 3D based on specific blueprints. Whether serving as companions for sick children; teaching kids with autism; or personal assistants helping elderly patients, humanoid robots have the potential of transforming the face of healthcare.

## Inter-disciplinary Therapies

Without doubt, the future belongs to interdisciplinary innovations. Examples include neurosurgeons at the University of California, San Diego School of Medicine and UC San Diego Moores Cancer Center using magnetic resonance imaging (MRI) guidance for delivering gene therapy as a potential treatment for brain tumors. This way the rest of the brain remains unaffected so the risk of the procedure is minimized. Medical professionals in any specialties have to start looking at the same medical problem from different angles and as medical education focuses on giving a very much specialized knowledge, social media and other digital technologies can help us get glimples into other areas looking for new ways of collaboration. Combining the knowledge of physicians from different specialties and cognitive computing could result in the best outcomes for patients.

# DESCRIPTION OF TRENDS

## Meaningful use of social media

Medical communication is something that affects all patients and medical professionals worldwide without exceptions. This is one reason why social media has the potential to become a huge "digital brain" making it possible to transmit, share, crowdsource and store medical pieces of information either for e-patients or medical professionals if such social platforms are used in a proper way. The power of digital/medical communication should be underestimated. Balance is needed as e-patients cannot and should not make a revolution without medical professionals being actively involved in it. This is why we have to train doctors do be ready for the digital era. Examples include Smart Patients, Patientslikeme and Sermo.

## Medical Tricorder

The concept of the medical tricorder that can diagnose diseases quickly as seen in the TV series Star Trek has been there for decades and there is a chance now to make it real. The Qualcomm Tricorder X Prize challenge hopefully leads to the development of a portable, wireless device that can monitor and diagnose several diseases and give individuals more choices in their own health. An example, Scanadu, can measure body temperature, heart rate, ECG, pulse oximetry and more basic parameters only by putting it to the forehead. What matters is patients should be able to access bioparameters about themselves and get the right devices/data to control their own health.

# DESCRIPTION OF TRENDS

## Microchips Modeling Clinical Trials

Switching from long and extremely expensive clinical trials to tiny microchips which can be used as models of human organs or whole physiological systems provides clear advantages. Drugs or components could be tested on these without limitations which would make clinical trials faster and even more accurate (in each case the conditions and circumstances would be the same). Microchips with living cells that model how a lung works are already available. The Organs-on-Chips technology has been developed for years and provides now a range of chips modeling organs. More complicated microchips that can mimic the whole human body are needed, and this ultimate solution could arrive soon.

## Multi-functional Radiology

Radiology will be quite different in about 10 years' time from what it is now as it is probably going to be a combination of imaging techniques and personalized diagnostics with real-time interventions. One multi-functional machine will be able to detect plenty of medical problems, biomarkers and symptoms at once. The machine used in the film, Elysium, tells the patient what percentage of their cells are cancerous with one quick check up. Further examples could include resting state and task functional MRI for examining cognitive patterns; large scale initiatives involving neuroimaging and the brain macro-connectome. The recently launched Human Brain Project could become even bigger than the Human Genome Project.

# DESCRIPTION OF TRENDS

## Nanorobots in Blood

Medicine today is based on interventions after the diagnosis is given. What if nanorobots in the bloodstream could intervene even before the disease appears? Nanorobots called respirocytes could be used to keep a patient's tissues safely oxygenated for up to about four hours after the patient had a heart attack; or serve as white blood cells; remove platelets or repair damaged cells. The opportunities are almost limitless. Moving it to the next level, modules that self-assemble inside the stomach could perform more-sophisticated diagnosis and treatment. The number and range of non-invasive operations could increase with such self-assemble robots.

## Optogenetics

Optogenetics is a neuromodulation technique using a combination of methods from optics and genetics to control the activity of individual neurons in living tissue. Optogenetics will provide new solutions in therapies. A recent study published in Science reported that scientists were able to create false memories in the hippocampus of mice. This is the first time fear memory was generated via artificial means. By time, we will understand the placebo effect clearly; and just imagine the outcomes we can reach when false memories of taking drugs can be generated in humans as well. The ultimate goal is to be able to modulate our senses, repair lost senses or even perform specific DNA targeting with femtosecond laser.

# DESCRIPTION OF TRENDS

## Personalized Genomics

Since the completion of the Human Genome Project, we have been envisioning the era of personalized medicine in which everyone gets customized therapy with customized dosages. The truth is that there are only about 30 cases when personal genomics can be applied with evidence in the background according to the Personalized Medicine Coalition. As we move along this path, we will have more and more opportunities for using DNA analysis at the patient's bedside which should be a must have before actually prescribing drugs. It means patients would get a drug and the dosage exactly customized to their own genomic background. Fast and accurate DNA sequencing is needed to reach this goal. The magic number will be 7 000 000 000 (global population) times 3 000 000 000 (number of base pairs in our DNA) equaling $2,1 * 10^{19}$ which is the number of base pairs that should be soon made available.

## Real-time Diagnostics in the OR

The intelligent surgical knife, iKnife works by using an old technology where an electrical current heats tissue to make incisions with minimal blood loss, but with iKnife the vaporized smoke is analyzed by a mass spectrometer to detect the chemicals in the biological sample. It means it can identify whether the tissue is malignant real-time during an operation without sending the biopsy to the pathology lab. A clinic in Germany started experimenting with an application using augmented reality on tablets in the OR. During operations, surgeons can see through anatomical structures such as blood vessels in the liver based on the patient's radiology images therefore they can perform more precise excisions.

# DESCRIPTION OF TRENDS

## Recreational Cyborgs

Cyborgs will be everywhere around us including a new generation of hipsters who implant devices and technologies in their bodies just to look better or have new functionalities. Advances in medical technology will not just repair physical disadvantages such as impaired eye sight but will create superhuman powers from having an eyesight of an eagle to having a hearing of a bat. While a patient wearing implanted defibrillators or pacemakers can also be added to the group of cyborgs, more cases when patients ask for the implantation of a certain digital device without having medical problems or only for augmenting human capabilities can be expected creating a biological imbalance due to financial differences.

## Redesigned Hospital Experience

Improving diagnostics and treatments is not enough any more, but we need to massively improve the healthcare experience whether the process takes place in a hospital or at home. The delivery of healthcare must acquire features regarding the customer experience from other industries. Clear, smart design ensuring comfort and privacy is needed. Transparent decision trees should also be available for patients after getting a diagnosis therefore informed decisions can be made with their doctors who would serve as partners in the care. See the NHS, Stanford Hospital or Ottawa Hospital for practical examples. And companies such as the recently launched Calico from Google will make attempts at reaching these goals.

# DESCRIPTION OF TRENDS

## Remote Touch

While the human touch is the key in the practice of medicine, after some time we will have to use remote touch due to the shortage of doctors and increasing number of patients. The force feedback technique used by the video game industry has the potential to be used in medicine as well. It has been demonstrated that biopsy sampling can be simulated in a 3D environment using a force-feedback controlled device. Surgeons could be trained with the technique to get better at a procedure even before operating on real patients. It could also assist medical students in improving in palpatory diagnosis.

## Robotic Interventions

The number of studies examining the use of robots in the operating room has been increasing rapidly in the past couple of years. Robots can be used in remote surgery, surgical rehearsal in pre-operative planning, intra-operative navigation, simulation and training, among others. It is clear robotic interventions can add a lot to the success of operations and different procedures. One of the best examples is still the Da Vinci system, but other robots in the fields of emergency response or radiosurgery are also available. We might soon see operating rooms with no people inside except the patient. Surgical instruments will be so precise in a few years' time that it will be impossible to control them manually, therefore robotic or mechatronic tools will be needed in order to reach the required accuracy.

# DESCRIPTION OF TRENDS

## Robotic Nurse Assistant

With the growing number of elderly patients, introducing robot assistants to care homes and hospitals is inevitable. It could be a fair solution for moving patients and performing basic medical procedures such as drawing blood. A prototype made by a US company combines robotics and image-analysis technology to find a good vein on the patient's arm and draw blood in a safe way. In the next step, it might also perform analysis on the blood from detecting biomarkers to obtaining genetic data.

## Semantic Health Records

The only way to constantly improve a system is to generate and analyze data to find solutions for improving it. The basic requirement of improving healthcare is everyone accessing their own medical/health data stored in semantic databases facilitating public health research as well. Semantic datasets could generate alerts about upcoming medical issues and potential complications. Ongoing efforts include ElationEMR, Curemd, Drchrono, Medopad and Practice Fusion.

## Smartwatch

Smartphones have not been able to replace pagers due to practical reasons, but an easily accessible wearable device might have the potential to make this step. A smartwatch could be used for consultations, making calls, sending messages, scheduling visits, as a pager or even for displaying fresh lab test results.

# DESCRIPTION OF TRENDS

## Telemedicine

In the digital era, the use of IT solutions in medical communication and even in healthcare is inevitable. In the future, it will not only include giving medical advice through online communication channels, but even sending life through the same channels such as DNA sequences over the Internet to synthesize proteins, viruses and living cells. We are not far from destroying all obstacles in exchanging medical information, drug, medical equipment or life itself through the so called biological teleportation and the advances of 3D printing.

## Virtual trials

In the era of open access and crowdsourced scientific information, we will have to find a solution for conducting clinical trials without experimenting on people gathering the same amount of information in the same quality as before but in a much faster, non-invasive, humane and reliable way. In order to reach this, a revolution is needed in medicine. Every country needs an E-patient Dave, a Jack Andraka and a Regina Holliday to fulfill these goals.

## Virtual Dissection

Medical students will study anatomy on virtual dissection tables and not on human cadavers. What we studied in small textbooks will be transformed into virtual 3D solutions and models using augmented reality. We can observe, change and create anatomical models as fast as we want, as well as analyze structures in every detail. Examples include Anatomage, ImageVis3D and 4DAnatomy.

# DESCRIPTION OF TRENDS

## Virtual Reality Applications

New disease categories due to the excessive use of virtual reality (VR) solutions in gaming and other industries will appear. Examples include virtual post-traumatic stress disorder (v-PTSD) which might be the diagnosis for gamers who participate in large virtual battles such as Call of Duty wearing VR masks and experience similar symptoms as those soldiers who fought in real wars. Expect to see ICD codes assigned to such new conditions soon. VR could be used in psychotherapy and people will be able to experience things virtually such as visiting distant places they would never be able to experience in real life. Patients could go through an upcoming operation step by step or choose a hospital based on its „virtual experience" package. Moreover, as the first bi-directional brain-machine interface became available, monkeys in an experiment could use a brain implant not only to control a virtual hand, but also to get feedback that tricks their brains into "feeling" the texture of virtual objects.

## Virtual-Digital Brains

Ian Pearson, in his book, You Tomorrow, wrote about the possibility that one day we would be able to create digital selves based on neurological information. It means we could upload our minds to a computer and live on in a digital form. As Google hired Ray Kurzweil to create the ultimate artificial intelligence controlled brain, this opportunity should not be so far away. We might have been searching for the clues of living forever in the wrong places so far.

# DESCRIPTION OF TRENDS

Wearable e-skins

Measuring easily quantifiable data is the key to a better health, therefore the future belongs to digestible, embedded and wearable sensors; the latter working like a thin e-skin. These sensors will measure all important health parameters and vital signs from temperature, and blood biomarkers to neurological symptoms 24 hours a day transmitting data to the cloud and sending alerts to medical systems when a stroke is happening real time. It will call the ambulance itself and send all the related data immediately. Examples include hydration sensors for athletes and intelligent textiles that change color indicating diseases.

# HOW TO PREPARE FOR THE FUTURE OF MEDICINE

1. Whether you are a patient or a medical professional, follow the main trends and try to be up-to-date by using digital methods.
2. Constantly look for solutions to improve your practice as a medical professional or your health as a patient.
3. Embrace digital in a comfortable way and use techniques that make your life easier and your work more efficient.
4. Look for examples and trends outside medicine as well.
5. Evidence backed by massive data is needed for any uses of digital solutions in medicine.
6. Hype in medicine has never been our friend. Strategically analyze trends and extrapolate to the future in a meaningful way.
7. Influence decision makers if your idea can make a change. Be bold and use social media channels to spread the word.
8. No matter how important role digital will play in our lives, human touch is and will always be the key in the doctor-patient relationship.

# FURTHER READING

1. Exploring Personal Genomics
2. Physics of the Future
3. Scienceroll.com
4. Social Media in Clinical Practice
5. The Medical Futurist Newsletter
6. The Singularity Is Near
7. Think Like a Futurist
8. You Tomorrow