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ORIGINAL ARTICLE

Aiming AI at a moving target: health (or disease)

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Abstract
Justified by spectacular achievements facilitated through applied deep learning methodology (based on neural networks), the "Everything is possible" view dominates this new hour in the "boom and bust" curve of AI performance. The optimistic view collides head on with the "It is not possible"—ascertainments often originating in a skewed understanding of both AI and medicine. The meaning of the conflicting views can be assessed only by addressing the nature of medicine. Specifically: Which part of medicine, if any, can and should be entrusted to AI—now or at some moment in the future? AI or not, medicine should incorporate the anticipation perspective in providing care.

Keywords Artificial intelligence · Data · Meaning · Deep medicine · Anticipation

1 Introduction

Medicine is focused on what is needed to maintain life. Medicine is an endeavor within the larger context of social organization of productive activity, of economic and political interaction, of culture. These and the environment, which used to be acknowledged as the dominant factor before the genetics revolution, affect medicine in all its aspects. AI in medicine is the shorthand for the meeting point between a new technology and what characterizes the practice of healthcare practitioners. Specifically:

- How to identify the specific talent and dedication healthcare demands.
- How medical education should be conceived and carried out.
- How to define experience—which medicine depends on—as well as blinding bias. (The "fresh eye" of a colleague or colleagues can help.)

While it is true that the beginnings of medicine are muddled—how much understanding was based on observation (empirical knowledge) vs. how much conjuring of the magical—the vector of development has been oriented towards ever more science and technology. Each step forward in knowledge acquisition and dissemination echoed in the practice of healing and maintaining a healthy life. Regardless of which new means and methods medical practitioners have adopted, major considerations of the larger context are kept in mind. Neither now nor in the past has the newest science and technology operated in a vacuum.

The fact that AI—which includes all who are involved (as scientists, technologists, or investors) in a particular form of science and technology claiming credit for artificial intelligence—is interested in medicine has many explanations. The simplest (a bit cynical): Healthcare is the second most important sector of the USA economy (ca. 20%, which translates into trillions of dollars). Economic justification (or exploitation) aside, the challenges of taking care of more and more people, affected by more and more conditions that new forms of life and work entail, are real. Everything that can help—provided that no long-term consequences nefarious to life or the world result—should be considered.

2 Can AI (really) make healthcare human again?

AI is omnipresent in medical journals and at professional conferences. "How Artificial Intelligence Can Make Healthcare Human Again" (the subtitle of the book *Deep Medicine*) is representative of the tenor of the discussion on the matter

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(Topol 2019). For an informed conversation of the subject, it is necessary to understand not only what healthcare is, but also what it takes to qualify as a valid perspective for the practice of medicine. The very large body of knowledge accumulated in medicine constitutes the foundation of medical education and for ongoing training. The foundation of medicine involves knowledge of science and technology in the broadest sense in which these words are used. Nobody expects physicians to be experts in plate tectonics, earthquakes, or volcanic activity. But physics, chemistry, and data processing are imparted to those seeking accreditation because they are relevant to dynamics of the living. The right to work in healthcare—the golden cage, as some see it—is associated with all the responsibilities the profession implies.

In addition to knowledge, which can be formalized—there are knowledge repositories available in the form of medical decision trees—there are skills to be acquired and maintained. No doubt, the new means and methods of knowledge representation and management associated with computation will help those in medical care effectively navigate the rapidly expanding acquired expertise characteristic of this particular form of human activity. By the nature of the profession, physicians exchange information and experiences because the outcome, in ideal form, is life, not a competitive edge in adjudicating profit or monetizing some new ways to help patients.

Before even entertaining the straight-forward question of what can be expected from a generalized deployment of AI capabilities, it makes sense to identify how human intelligence partakes in the discharge of the duties of healthcare professionals. This applies to everyone, from those maintaining sanitary requirements (in offices, clinics, and hospitals) to nurses, assistants, physicians, and, of course, administrators of healthcare businesses (the highest paid segment within the medical complex), including insurance companies.

For the physician's cognitive profile, it is useful to know that the IQ of medical doctors is at the level of professionals in the natural sciences (e.g., physics, mathematics, biology), of lawyers, and of college professors. Even those doubting the relevance of the IQ metrics would accept that the span between 110 and 130 and above testifies to a rigorous selection process. The 10 years needed for full accreditation as a medical doctor—study required for a degree in medicine and the following years of residence and internship—testify to a sense of dedication and responsibility. It also explains their analytic skills, the ability to interpret data presented in alphanumeric form or in visual representations, their tendency to seek associations and correlations, to make inferences, and to question themselves. It is an activity that implies professional ethics—pathogenesis and ethos should be seen in their connection—commitment, and communication skills. For all practical purposes, doctors are small business managers. Some are engaged in research and in publishing their findings and experiences. Being science, applied technology, and art at the same time, medicine is basically grounded in the interaction between healthcare provider (physical therapist, nurse, surgeon, physician, etc.) and those who seek qualified help in maintaining or regaining health. A concept that frequently comes up, especially in the context of contemplating automated medical procedures, is emotional intelligence. In particular, empathy—to feel for the other, and to feel what the other is feeling—is emphasized.

3 Knowledge and empathy

On this note, a first observation begs for our attention: Medical education imparts knowledge, but is also supposed to make students aware of the role that empathy plays in the day-to-day healthcare delivery. Research has shown that during medical education, empathy actually deteriorates (Neumann et al. 2011). Despite the evidence, the "why" of this situation is almost never addressed. It is the result of the machine model, or of "conveyer-belt medicine" (Elia and Aprà 2019) not only adopted in the practice of medicine, but also driving medical education. Mechanics and assembly line workers do not need empathy to fix or make cars, airplanes, or boats. For medicine, the loss of empathy results in the lower effectiveness of treatment. Empathy supports the effort to engage the patient. This observation will serve us well when we examine the expectation that AI will free the physician from some tasks, and thus give them the opportunity to better express empathy.

All these background factors—especially empathy—are essential if the task of evaluating how AI will affect medicine is taken seriously. In a different context, it was argued that while the qualifier "artificial" in AI is beyond controversy, intelligence is not (Nadin 2018a). To automate activities in which intelligence, in some of its many forms of expression, is involved is not the same as making intelligence available. Medicine is a good example of this. Those practicing it are confronted with the definitory aspect of intelligence: to understand *before* you act, not necessarily to act in a manner that afterwards *seems* intelligent (Nadin 2018b). This is what a physician does: associating symptoms with possible causes against the background of the patient's personal narration, i.e., the timeline of events from birth to the moment when the consultation takes place. Understanding is context dependent and predates the action, i.e., the treatment. That is, understanding based on information is anticipatory. For this understanding to arise—intelligence is a process—there are quantified aspects (measurements) to be considered; there are also qualitative assessments to be made; and there is the empathy. In a description that intentionally goes to the extreme, empathy means that a doctor experiences what the patient is going through. The pain of the others becomes the doctor's pain. They die with those dying in their hands. This is not poetry. Let us recall the mirror neuron cognitive model (Gallese et al. 1996; Rizzolati and Craighero 2004) and its experimental evidence. The configuration of neurons in a learning situation imitates that of the teaching person. Other scientists submitted to the scientific community and to medical practitioners proof that the mirror neuron system underlies empathy (Preston and de Waal 2002; Decety and Jackson 2006; Jabbi and Keysers 2008).

Based on this observation alone, not on sentimental descriptions of the role of emotions, we understand why the burnout among those who work in medical care is higher than in other segments of the population. We also understand why the suicide rate exemplifies the existential nature of the activity of physicians, regardless whether they view their patients as machines in need of fixing, or as living persons in need of individualized interventions of genetic or epigenetic nature (self-repair, for instance). Diagnostic procedures, some well-defined (as in differential diagnostics) involve the empathy component. Healing is often (but not always) self-healing, in the reality of the integrated human being in which each cell is literally involved. To ascertain that empathy will again be made possible when AI takes care of tasks that can be automated is indicative of "machine theology": we made them, they can replace us, provided that we join the "church" (or the cult, as deep learning has become).

4 An obsession with measuring

On a daily basis, the medical industry trumpets yet another milestone in automating, for example, the evaluation of radiology images, MRIs, and CT scans. This is worthy of acknowledgement because better descriptions (through measurement or visualization) are helpful. But it is a self-deceiving trend. The obsession with measurement, with more data, created a bottleneck in medical treatment—and made the radiologist the best-paid medical practitioner. Now, deep learning is supposed to do the same: evaluate data, but at a fraction of the cost—that is what automation means—in disregard of the disconnect between the living who is undergoing change, and the non-living object (here, the AI-based machine) that is monitored to avoid breakdowns.

To associate personal history data (each patient brings a history, from birth to the current condition, with himself or herself) and imaging data—the visualized present—is a goal worth pursuing. To assume that it can be attained through AI (in the classic definition) or deep learning is more a wish than a conclusion based on understanding what such technologies can achieve. The anamnesis (the patient history) is an interpreted timeline: it invites a new evaluation, i.e., considerations expressed at the semantic and pragmatic levels of the representation. No computation based on the Turing machine—operating only at the level of the syntax—is appropriate to the task. The expectation that the newly generated visual image (e.g., of a fracture, a blood clot) will be delivered together with its interpretation is to imply that "There is a god in the machine", since context escapes mathematical description—without which no computation is possible.

A mathematics that interprets itself is a nice idea for science fiction, but otherwise, to accept such a development is wishful thinking, at best symptomatic of ignorance. Moreover, what makes the new optimism (some might characterize this as an "expression of ignorance') even less acceptable is a limitation that goes deeper: each living being is unique. There is no way to generalize within the "idiographic" (Windelband 1894)—the open-ended space of uniqueness. To understand that the normal can be bad for one person, or the abnormal good for another, only suggests the implications of the uniqueness. To deal not with quantities, but with meanings is not within the capabilities of AI or algorithmic computation. Yet, it is another expectation waiting to be acknowledged. It might well be that AI predicts death better than physicians can (Weng et al. 2019), but to fight death, and often succeed against the odds, is quite different in meaning from death by numbers.

5 How well do physicians and patients understand what AI is?

Understanding the science behind AI is the prelude to the decision of whether it makes sense to invest in learning how to use it. Science, and in particular medicine, is driven by optimism. No science worthy of its name starts off with "It is impossible". No medical assessment ends in less than optimistic terms, even in cases of the still incurable. All those understandings of reality manifest in the knowledge of hydraulics, pneumatics, optics, electricity, and combustion, which medicine adopted as acceptable descriptions of the human being, originated in the human mind. They were subject to being understood and were tested in reality. For a time, knowledge seemed independent of the originator. Like: "It is real that intestines are like irrigation canals", therefore, if you experience pain because they get clogged, the physician has to help open them up. Or, to come to our time: the brain consists of neurons; therefore, our mathematical description of the neuron applies to our brain and explains how it works. From here to the "theology" of neuronal networks, of deep and deeper learning, the leap is pretty dangerous if not enough knowledge is used. Hinton's (2019) optimism regarding the capabilities of machines, can be celebrated (at least in its spirit), but not automatically generalized to medicine, a domain that transcends the mechanistic perspective. The "new Descartes", not of mechanical clocks (the machines of the sixteenth century), but of artificial neural networks (Hinton 2018), might realize, as a potential patient (and who is not a potential patient?), the difference between the living (and its intelligence) and the machines supposed to help doctors and patients.

Here, we should take note of an interesting parallel: What distinguishes the training of neural networks (i.e., machine learning) and the training of medical professionals. The energy expense for training a physician stands in no relation to that used in machine learning. Deep learning is driven by a huge amount of data and takes place at an impressive cost of high energy use. The outcome is the convergence on a specific diagnostic. The learning for becoming a physician is focused on making inferences possible: from a specific case to the generality (sometimes a spectrum) of various conditions. The open-endedness of medical conditions is met by the adaptive nature of the physicians. Machines can be extremely precise, but they do not evolve. Therefore, the dynamics of life—individual change over time, disease included—escapes their processing powers.

Neither Thomas Bayes (*The Problem in the Doctrine of Chances* 1763; nor Adrien-Marie Legendre (with his "least squares method", *Méthode des moindres carrés*, 1805); nor Pierre-Simon Laplace on probabilities (1814), nor Markov (1906) analyzing a poem without realizing that the technique would become a powerful tool in the age of data processing); and probably not even the polymath Alan Turing (1950), had an inkling that healthcare would eventually be affected by their descriptions. "The Beginnings of Artificial Intelligence in Medicine" (Kulikowski 2019)—a very thorough report—reflects the understanding of healthcare as a heterogenous knowledge domain (Kulikowski was part of the beginnings) associated with skilled performance, some subject to automation.

Within Artificial Intelligence in Medicine (AIM), physicians are identified as problem-solvers, using ad hoc heuristics. Their reasoning, in this view, is based on pattern recognition. Physicians' decisions are the outcome of clinical data processing and of interpretations often tested within the feedback mechanism of the patient–doctor interaction: "How does this treatment work?", "How does this dietary prescription affect my condition?", etc. The boom and bust (called "AI Winter") in AI is reflected in the waves of optimism (excessive at times) that followed each disappointment, especially in the practice of medicine.

6 The role of ontology

If there is one undeterred development, it is the development of ontologies, the common medical vocabulary, in some machine interpretable definitions. The National Library of Medicine (NLM) in the USA recognized early on (in the 1960s) that the promises of data processing would come to fruition only if a mapping from the language of healthcare professionals to computation could be made available. Chances were close to nil that the mathematicians, logicians, and computer scientists who dedicated themselves to AI were also competent in medicine. Moreover, the large repositories of knowledge (biomedical literature, vocabularies, encyclopedias, etc.) could not be implicated in the effort without providing access in some machine language. The WordNet (George Miller at Princeton University, 1980) was an example of how to organize language in machine-readable logic. The foundation for AIM was provided by the Medical Literature Analysis and Retrieval System (MED LARS) and its successors (MEDLINE), as well as by the associated search engine (PubMed). Physicians and all those involved in medical care developed a language appropriate to that aspect of reality—health—that made their activity necessary. To describe the patient in a language that supports easy retrieval, reuse, sharing, and eventually actions is an accomplishment for which medicine never gets enough credit. Ontologies describe what is. Celsus (25 BCE-50 CE) referred to color (*rubor*), heat (*calor*), shape (swelling, which is *tumor*), and pain (*dolor*) to produce the ontological equivalent of inflammation.

The challenge is not to translate the early description into machine language, but to provide means to translate all the ambiguities into its language. Intelligence entails understanding, which is a mapping from a description—words, images, sounds, etc.—to some action. Data describe the formal aspects of the real: numbers identifying what kind of red, how high the temperature, how fast the heartbeat, etc. Dictionary definitions map to common use: how patients and physicians describe an inflammation. Meaning is at work with respect to action (the targeted therapy): what to do to address the processes leading to an inflammation. And, no less important: how to make sure that "fixing" something does not lead to "breaking" something else.

Putting in the proper light the language involved in "reading" the symptoms, in issuing a diagnostic, and in formulating a course of action (the desired remedy) is relevant because in the final analysis, AI, in both its symbolic and statistical embodiments, is driven by ontologies. ImageNet (Fei and Russakovsky 2007), the visual parallel to WordNet, made available millions of annotated images, organized in a large-scale Hierarchy Image Database (HID). The AlexNet (Krizhevsky et al. 2012) and the OpenImage (Google in 2016) helped in the integration of word and image which, at least for medicine, was a necessary condition. The dictionary defines an inflammation as a local response to cellular injury. It defines its symptoms as capillary dilation, leukocytic infiltration, and swelling. Ontologies of inflammation—here used as an example (inspired by Pisanelli 2004)—are more than dictionary descriptions. They provide data actionable upon. There are agents (physical, chemical, biological) that cause an injury. Affected blood vessels and adjacent tissue change their state due to the stimulation. The removal of the injurious agent and the stimulation of repair processes are a course of action that the physician adopts in awareness that the meaning of the inflammation is not the same as the data describing it. The variety of attributes—amount of infiltrated substance causing the injury, type of lesion (superficial, deep, etc.), duration, and similar—of the process is evaluated in the context of the patient's condition. A compromised immune system, suggests a different path of medical intervention than the immune system of a healthy patient. The Unified Medical Language System (UMLS), which the National Library of Medicine initiated, is a repository that helps in defining clinical guidelines. Information processing supports retrieval, either by the human physician or by some intelligent agent.

Without any doubt, statistical inferences, on whose basis deep learning comes about, and quantitative meta-analysis have contributed a lot to medical knowledge acquisition and accumulation. They also made AI in medicine a reality, regardless of anyone's skepticism. Imaging, as a diagnostic tool, is an area where the interpreting radiologist and AI—deep learning trained on huge data sets—came to compete with each other. Automating malaria detection by making possible the assessment of malaria parasites in a blood sample is based not only on processing vast amounts of data, but also of having the proper ontology in place. What a digital camera attached to a microscope "sees" and expresses in actionable data is defined through the appropriate ontology.

Ontologies trail behind natural language processing through the way in which the syntax-driven computer is associated with dictionary-defined meanings of words. Take suicide for example. Suicide, a major cause of death in the USA, associated with mental health challenges, cultural aspects, and socioeconomic conditions, is rarely (if ever) a spontaneous action. Within every suicidal person there is a narrative of behavior and there are specific forms of expression. AI-driven "scanners", combing not only through social media messages (*scraping*, as it is called), but also through health records, could identify suicide risk. The fact that privacy is at stake, and the decision of what weighs more—prevention or risk—cannot be ignored. This applies to all aspects of monitoring: wearable devices, communication (digital media, such as e-mail, digital telephony, messaging, etc.).

7 Medicalizing the healthy

Of course, AI can fully automate the burdensome bureaucratic overhead of regulations (EHR and even part of FHIR) and free the physician from the tasks of typing or voice inputting to recording devices. But even for this worthwhile task, the dangers of abandoning privacy, which medicine has so far protected, are real. The mobile wearable devices are a promise that makes those in the AI business salivate (Sim 2019). Sensors continue to diversify. Their sensitivity is increasing. Access to data is almost instantaneous. Connected to networks of all kinds and to the cloud, such devices are the new promise of good sleep, good nutrition, good exercise, entertainment escaping loneliness—you name it, they do everything. But society learned that the dangers associated with their use are often as great as the opportunities.

Medicine should not begin with measuring more and more, but *with prevention*. This very simple premise can mean many things, among them, the extreme: measure everything every time. Lisa V. Hamill's tweet (2019) on the matter went viral:

> The USA has been accused of an over-focus on tests and drugs, practicing expensive care with less than stellar results. Now we turn to "medicating good health?!" You can't be "healthy" without monitors and tests? You need 8 monitors on your wrist to tell you to exercise/lose wt?

There is ample evidence for associating the obsession with all kinds of devices (from the innocuous Fitbit™ and Applewatch™ to sensors that monitor sleep, eating patterns, sexual activity, for instance) with possible negative effects. Start with the psychosis—e.g., blood pressure does not improve through continuous checking, but becomes an obsession—and continue to a large number of interventions not really meaningful since they could actually undermine a person's condition. Mandrola (2019) reports on a case in which digital monitoring revealed some abnormality, usually ignored, that prompted an intervention that led to a stroke in a retired but still functioning farmer, thus forcing him into a nursing facility.

Even the proponents of phenotyping as the backbone of deep medicine realize that more data are a "kitchen sink" obsession that can backfire. "Creation of revenue", as Muse and Topol (2019) call it, is a delicate way of describing medicine driven by greed. Illich (1974), critical not only of the education system, but also of medicine, uses the word *iatrogenesis* to describe clinical harm from excessive screening—only because we can screen and can carry a device on us. Digital implants are tampered with; malice was injected into medical imagery. Medical data breach and interruptions in medical services are in line with acts that not only cost money, but also undermine the social fabric. Insurance fraud, sabotage research, political malice, and media manipulation are not the same as injecting a lung cancer into a CT scan. A generative adversarial network (GAN), which is a neural network within which the distinction between real and fake samples serves as a learning process, could be used not only to distinguish between a cat and a dog, or between healthy and unhealthy cells, but also for malicious purposes (Mirsky et al. 2019). It can affect picture archiving and the communication systems (PACS) that manage CT and MRI scanner data. All this sounds more like escalation of various societal conflicts than progress in healthcare.

It is a sign of responsibility that there are voices warning against the consequences of creating dependencies, some of which can lead to harm. To repeat: medicine and ethics cannot be separated: pathogenesis and ethos are co-substantial. On the other hand, the amount of dedication and enthusiasm of those who examine the new opportunities is encouraging. New ideas come to the fore; experiments are conceived and carried out; the optimism inherent in science extends into the medicine of the time of AI and of many other scientific and technological innovations.

8 Deep medicine revisited

The subtitle of the book *Deep Medicine* provides an image of what the medicine of our time (and of the future) might become. "How Artificial Intelligence Can Make Healthcare Human Again", is an issue that Topol (2019), himself one of the most influential authors addressing the broad public tries to answer. Topol, a distinguished cardiologist (still practicing 1 day a week) and an early adopter of digital technology in medical care, proudly discloses his involvement with companies producing such technologies. He follows the path of those scientists (such as Marvin Minsky, Craig Venter, Stephen Hawking, Carl Sagan) who became the public face of new fields of human inquiry. He joins physicians who cover medicine for TV networks and major media outlets. In 10 years of sharing information via Twitter, Topol single-handedly produced over 18,000 messages (the so-called "tweets"). He is informed about what is taking place, and he is passionate about a human-face medicine. With the ill-conceived notion of deep medicine—following in the footsteps of calling the shallow techniques for processing statistical data "deep learning"—Topol submits a model of medicine that can be criticized but not ignored. His rather vivid prose (with good examples from his practice) is meant to describe a three-prong approach:

1. A complete description of the individual. In his view, deep phenotyping means a full mapping—from the data pertinent to one's medical condition to social, behavioral, etc. records. Of course, DNA, RNA, proteins, microbiome, etc. are part of this mapping.
2. Deep learning—including visual patterns, processing of data associated with symptoms, even nutrition patterns. Medical care shifts from direct contact between the physician and patient to a virtual interaction.
3. Deep empathy, which can result from freeing medical caregivers from anything that interferes between them and their patients.

Reviewed by everyone, in almost every publication, the book is significant for assessing the level of understanding that both medicine and the new technologies have summoned. The goal is to save medical care from a condition of subservience to regulation, economic pressure, and technological dependence. Given the fact that everyone's life is, in one way or another, sooner or later, affected by the state of medical care, the new paradigm deserves full attention—no less than AI itself or, for that matter, computation. (A previous paradigm was called "Digital Health".)

Practitioners and academics debate whether "…artificial intelligence makes doctors obsolete?" (Goldhahn et al. 2018), not so much because they understand the implications of the question, but rather because they are under pressure—from everyone, patients included. The record of achievements—in image analysis (X-rays, retina scans, MRI, etc.), in genetic assessment (based on genome scans), in clinical decision support (such predicting septic shock), virtual nursing (keep patient under remote observation via the internet), robotic surgery (laser eye surgery is in the lead), and more—is as impressive as the record of failures. IBM's Watson Health Division is the first example that comes to mind. At this juncture, we could reference thousands of reports on achievements, but no less on failures. However, their meaning will escape usefulness. We will not know, from the reporting, to which extent they are accidental or reflect a new horizon. In order to understand what such performance means, we have to understand the epistemological background against which we can evaluate them.

9 The question of entropy

More important from the perspective of medicine and its exposure to computation and AI is yet another contribution by Shannon (1938, 1948): the realization that data transmission is affected by what the second law of thermodynamics describes. As a matter of fact, entropy, which characterizes the disorder of a system (to use a simplified description), affects data transmission. With this additional aspect in mind, it becomes evident that data processing within a relay circuit, an integrated transistor circuit, in a liquid (Leonard Adleman's test tube DNA computation), in an artificial muscle, in any medium is subject to limitations resulting from the entropy of the medium used. Quantum computation—the new frontier in computation—forced those who are trying to achieve the performance increase it promises to invest a lot in securing an environment in which entropy can be controlled (Nadin 2014).

Since the living is negentropic—its entropy does not increase as in physical systems—the question is whether computation, i.e., the automated mathematics it facilitates, can properly describe living processes. By extension—since AI, regardless of its kind, is achieved through computation—it is fair to question the extent to which it can do more than assist a physician in addressing the state of a patient by providing the benefits of automated data processing. But which data? All that there is? Or actually the significant data that a good doctor identifies?

Like everything ever invented, the computer is a deterministic device. For everything of deterministic nature in the dynamics of life, computation-based means and methods are useful. Just for the sake of providing some examples: extreme precision surgery, guided by large sets of numerical descriptions, benefits from computer-driven surgery tools. The robots deployed for such types of interventions have reached a performance level that cannot be matched even by the most experienced surgeons. Things are not so clear-cut when it comes to tasks that by their nature qualify as non-deterministic. Illness, as the medical community realized over many centuries, is an ill-defined problem. It does not suffice to measure more and more and to process higher and higher volumes of data to assess a patient's condition—not to say to define a course of action that might cure the patient, or at least provide means to alleviate many aspects of illness. Topol's book, the "bible" of this moment (in which one theology succeeds previous ones faster and goes even further) ignores all these questions.

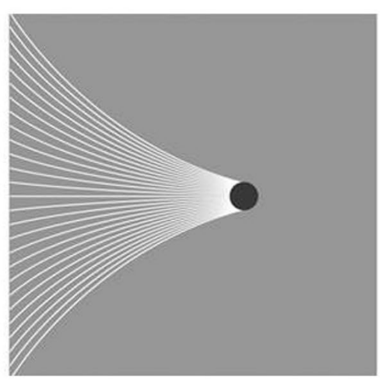
10 Anticipation: an unavoidable grounding for medicine (AI or not)

In the process of transforming the human being into a machine, AI (and computation) seems to gain momentum. Alternatively, those who would like to free medicine from the condition of being a repair shop for human beings ascertain the need to change the perspective of medicine. Topol does not belong to those who recognize the need for a new perspective. We argued in favor of anticipation-grounded medicine as the necessary alternative (Nadin 2017, 2018b) (Fig. 1), and even tried to engage Topol in a discussion (International Conference on Anticipation and Medicine, Delmenhorst, Germany, September 26–28, 2015).

Just for the sake of clarity, the meaning of anticipation in the current practice of medicine is limited to progressively earlier symptoms and higher intensity of disease from generation to generation. Anticipation, in the broader sense ascertained in this study, is definitory of the living. It underlies evolution and as such it explains why diminished anticipatory expression results in conditions that become the subject of medical care. If and when medical care was to overcome its reactive obsession, medicine would evolve from an almost exclusively mechanistic activity to a proactive practice of well-being. Healing could replace fixing.

Understanding how such anticipatory processes take place—let us say in the relation between blood pressure and the heart rate—and what the practical implications of this understanding might be is of immediate practical consequence. Immunotherapy, for instance, is an expression of this interest in anticipation. Very few medical practitioners, mainly in alternative medicine, try to engage the body instead of attacking real or presumed causes through

Fig. 1 Anticipation-grounded medicine corresponds to the anticipatory nature of living processes



medication (sometimes drastic) and surgery. Neurology, neurosurgery, psychosomatics, and psychotherapy, gastroenterology, and psychology are medical endeavors in which the anticipatory perspective is slowly gaining traction. Consequently, some simple inferences became possible. For example, the realization that anticipation of stressful situations—such as exams, natural disasters, taxing conditions—accelerates cellular aging led some physicians to address behavior (and life choices), not the chemistry of stress. Anticipation of back pain (extremely frequent) seems to predispose to back trouble (anticipatory postural adjustments are affected). Neuroticism (the tendency to experience negative emotions) affects brain processing during the expectation of pain. Fibromyalgia is an expression of pain anticipation. The pathophysiology of autism (in infants) or of Alzheimer's disease evinces the consequences of skewed anticipation. The change of perspective led to a change from reactive healing to proactive treatment.

The anticipatory perspective as the alternative is not as comfortable as the successful, though beaten, path of physics and its promise for technology. One cannot expect abrupt abandonment of the huge investment (time, energy, money, human lives, and the lives of animals used in experiments) in taking the wrong turn. In the context of rapid scientific advancement, and in view of increased awareness of sustainability, we can hope for a shorter time for ascertaining a complementary view. The urgency of applying it to situations for which physics- and chemistry-based medicine is not adequate cannot be overemphasized. The aging of the world population is unavoidable; the degeneration of the species—expressed in, among other ways, systemic disorders and debilitating spectrum conditions—is probably an even more critical aspect. Again: sustainability. The energy expenditure of most reactive procedures is so high that the carbon footprint of medicine compares to that of industrial activities.

Two pre-requisites for redefining medicine ought to be spelled out at this juncture:

1. Medical practitioners will find value in stepping out of their comfort zone only to the extent of seeing their efforts rewarded (success rates included).
2. Those dedicated to research of anticipatory processes will have to deliver, in clear language, operational means and methods to their colleagues in healthcare.

If both are realized, medicine will change. Otherwise, it will take a deeper crisis than the current one before medicine progresses from reaction-driven physics-based practice ("fixing" the patient) to a proactive, anticipation-based dedication to the well-being of the whole person. Indeed, medicine, and those working hard to help healthcare practitioners, needs to rediscover the living as having a condition different from the non-living. Of not being a machine! AI and computation should be considered for those situations in which our knowledge of the living is still so rudimentary that we have to make use of physics and chemistry, instead of involving biological means for maintaining health or for healing.

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