Today, we find ourselves on the brink of a technological revolution. In the coming years, artificial intelligence is bound to impact almost every industry and endeavor, forever changing the way we live and work. And the field of medicine is no exception. Does that mean we’re heading toward a world where, if we get sick, we’re seen by robotic doctors and nurses? Well, no, not exactly. We may eventually be able to cede total control to other types of AI – say, driverless cars – but medicine will always require some form of human oversight. The best possible future for medicine is one in which humans and algorithms are each able to use their unique strengths and work together to improve patient care and health systems. One day, AI may be able to make accurate and complete medical assessments. But we’ll need humans to apply those assessments and establish the deep, trusting bonds with patients that are so often missing today.

In these blinks, you’ll learn how machine learning saved a newborn’s life; how AI can predict depression using your smartphone; and how we could have hospitals with doctors but no patients.

Robert was a fairly healthy 56-year-old. But one afternoon, he experienced what doctors call a “ministroke” – his face went numb, and he began having trouble seeing. His doctor told him to continue taking an aspirin every day, as he had been before. Unsatisfied with this prescription, Robert went to see a neurologist, who then referred him to a cardiologist. That’s when he found out that he had a patent foramen ovale, or PFO, a tiny hole in the wall separating two of his heart’s chambers. The cardiologist claimed that this condition was the cause of Robert’s ministroke, and that he needed surgery to close the gap in his heart. But Robert wasn’t so sure. The key message here is: Health care requires a shift from shallow medicine to deep medicine. After seeing the first cardiologist, Robert came to see the author, Eric Topol – also a cardiologist – for a second opinion. Topol was shocked by the original assessment; one in five adults have PFO, and the condition isn’t connected to strokes.

So he and Robert worked together to determine Robert’s real issue and found it was atrial fibrillation, which can be treated with a simple blood thinner. Robert’s situation exemplifies what Topol calls shallow medicine, in which burned-out, depressed doctors don’t take the time to develop real connections with their patients and make holistic assessments. Average clinic visits in the United States, for instance, last just seven minutes. Perhaps as a result, there are about 12 million significant misdiagnoses per year across the country, and up to one-third of medical operations performed are unnecessary. Patients are suffering, but so are the people who treat them. One in four young physicians experiences depression, and almost half of American doctors today have symptoms of burnout. This condition greatly increases the risk of medical errors – and even leads to physician suicides. To address these issues, we must start the shift from shallow medicine to deep medicine. This shift occurs in three fundamental ways. First, medicine will require physicians to deeply define each individual with as much of their relevant personal and health history as possible. Second, it will require deep learning on the part of artificial intelligence, to augment doctors’ diagnostic abilities and automate repetitive tasks. And finally, deep medicine will require doctors to practice deep empathy – seeing patients as real people, not just as problems to be diagnosed.

Artificial intelligence in medicine may seem like part of some distant future. But in fact, it’s already being used to save lives. In one case, a healthy baby boy went home three days after birth. Five days later, his mother rushed him to the emergency room of Rady Children’s Hospital in San Diego. The newborn was experiencing constant seizures that were only getting worse. As things were looking bleak, a sample of the boy’s blood was taken to the lab for rapid whole-genome sequencing. In just 20 seconds, AI processed the boy’s entire medical record. Then, machine-learning algorithms sifted through the data, eventually hitting upon one rare genetic variant that could be causing the boy’s seizures. Treating him with vitamin B6 and arginine supplements could override this gene’s effects. The key message here is: Artificial intelligence could greatly benefit health care, but it has its limitations.

Thanks to this treatment – and the rapid work of AI – the newborn’s seizures ended. He’s now perfectly healthy. This case shows that AI, working with human doctors, has lifesaving potential. But before waxing too rhapsodic about AI’s capabilities, it is essential to consider its limitations. First and foremost, AI depends entirely on the quality of its data; this is all it can use to learn and make predictions. Most AI works with structured data that’s standardized and searchable. Medical data, however, is often unstructured and narrative in nature. Inaccurate or incorrect labels can easily mess with an algorithm’s output. Also, AI isn’t creative; it can’t dream up new solutions to problems. Once, Topol was treating a 70-year-old man suffering from extreme fatigue. A CT scan revealed that his right coronary artery had narrowed by 80 percent. Topol was confused since this issue doesn’t normally cause such severe fatigue. He explained the situation and offered to put a stent in the blocked artery, which the patient agreed to. The very evening of his operation, the patient could already walk several blocks without feeling fatigued. He reported that he felt stronger and better than ever. A computer algorithm could never have recommended that procedure, since there were no precedents for this man’s specific situation. Current AI has some critical limitations that will never allow it to fully replace human doctors. But it can still greatly benefit medicine.

Many people think of doctors as infallible – almost superhuman. But just like everyone else, doctors can have implicit biases that cause errors in both diagnostics and treatment. Take the representativeness heuristic, a bias that causes people to make decisions based on their past experiences. It might lead a doctor to misdiagnose one illness for another – especially if he isn’t carefully examining all of a patient’s symptoms. Perhaps even more insidious is the overconfidence bias, which causes physicians to believe their diagnoses are correct more often than they actually are. All of these biases come into play when people use intuition to make snap judgments, as doctors often do when diagnosing patients. It can take years of experience to lessen the impact of these biases – or, perhaps, the help of AI. The key message here is: Doctors can use AI to help Deep Mimedicine prove their diagnoses. What do you do when you’re experiencing symptoms but don’t know the cause? Most likely, you turn to Google or an online symptom checker. There are a lot out there, but they aren’t particularly accurate just yet. A 2015 study of 23 online symptom checkers found that only 34 percent of them could come up with a correct diagnosis. At the moment, it’s difficult for machines to make comprehensive, holistic diagnoses. But they do well when diagnosing specific types of illnesses. Take the Face2Gene app, which can help diagnose more than 4,000 different genetic conditions by recognizing particular facial features associated with them. Sixty percent of medical geneticists and genetic counselors are already using the app in their practice. To make broad use of AI for medical diagnostics, we must transform the practice into a data-driven science. This will require a massive amount of information to be collected on each individual – ideally, starting from the prenatal stage and continuing throughout the entirety of our lives. Of course, data collection on a mass scale brings up valid concerns. If they had access to detailed data about patients, insurance companies could use AI analytics to partition people based on their health risks and create steep differences in coverage rates for higher-risk patients. Undoubtedly, government regulations will be necessary to prevent these abuses of patient data. But we shouldn’t let the concerns outweigh AI’s potential contributions.

In the next few blinks, we’ll look at how AI can assist specific types of medicine.

Have you ever gone to a doctor who barely even looked at you during your visit? Who instead spent most of her time typing notes into a computer? If so, she was probably updating your electronic health record, or EHR. EHRs were developed to make clinicians’ lives easier. Instead, they’ve become a barrier to doctor-patient communication. Fortunately, things like the EHR are ripe for automation. A type of machine learning called Natural Language Processing could potentially be used to tape and transcribe all the words exchanged during a doctor visit. Doing so would free up doctors’ time so they could focus instead on the person sitting in front of them. Processing huge amounts of data is AI’s ultimate talent. And there are several types of specialist doctors who could truly benefit from it.

The key message here is: Diagnostics based on pattern recognition could make great use of AI.

Every year, two billion chest X-rays are performed worldwide. These scans can be difficult to read, given that scarring or collapsed lung tissue can obscure other issues. But AI, with its ability to quickly process and interpret terabytes of image data, could potentially read these scans with a high degree of accuracy. One study trained a machine learning algorithm to classify over 50,000 chest X-rays as either normal or abnormal. Used widely, this algorithm alone could help radiologists determine which scans deserve a closer look and which don’t. With all the time saved, radiologists could perform other valuable work, like speaking directly to patients – something quite rare in current practice. When used in tandem with human radiologists, algorithms can help achieve greater diagnostic accuracy than either one operating alone. This is also true for pathology and dermatology. Pathologists, who interpret samples of human tissue to diagnose disease, can make use of PathAI, a tool for analyzing slides. This tool boasts an error rate of 2.9 percent on its own, but when working with a human pathologist, that number drops to just 0.5 percent! In dermatology, there’s a slightly different problem. The US has relatively few practicing dermatologists, so about two thirds of all skin conditions get diagnosed by primary care physicians instead. As a result, error rates are astonishingly high. Here, machines could step in to diagnose specific skin conditions. In fact, one 2017 paper has already determined that an algorithm can outperform dermatologists at classifying cancer and identifying melanoma.

Algorithms thrive on data – the more and richer, the better. After all, it’s from this data that they identify patterns and determine answers. Much of what goes on in the clinical environment, however, doesn’t involve patterns. Doctors are constantly making assessments, creating plans, and communicating with patients and their families. So where does AI fit in? Well, we know that current AI works best when it’s applied to narrow functions instead of broad ones. And there are certainly plenty of narrow functions involved in the everyday lives of most doctors. The key message here is: Doctors who don’t primarily work with patterns could delegate some routine tasks to AI. There are many different types of doctors who stand to benefit from AI. But for now, let’s just look at cardiologists.

A recent deep learning neural network has been proven to diagnose heart attacks at around 90 percent accuracy. Other technologies are also helpful when it comes to measuring heart rhythm. One device, the iRhythm Zio patch, is a BandAid-like device that’s placed on the chest. Inside it is a chip that captures information about every one of the wearer’s heartbeats for 10 to 14 days. With this information, cardiologists can more easily assess heartbeat irregularities and other issues. Transforming heart rate and rhythm into digital information is one thing; it’s much more difficult to do the same for a person’s mental state. Yet, AI can also be used to assist mental health professionals and people with mental health disorders. Many factors, including cost and availability of psychiatrists in a particular region, prevent people from seeking mental health care. Mental health chatbots, however, can provide a feasible alternative to therapy in such cases. These chatbots often make use of cognitive behavioral therapy, or CBT, which is traditionally based on in-person conversations but can instead be brought to our devices. Some studies have found that people even prefer to speak about sensitive, personal issues with chatbots over actual humans! In addition to chatbots, AI can be used to help diagnose mental health conditions like depression, which over 10 percent of people experience globally. One algorithm called Deep MDedicine eepMood, for instance, was able to predict depression with high accuracy just by studying a person’s smartphone keyboard patterns.

Will humans always require hospitals? The answer might seem obvious. But while it’s true that we’ll always need ICUs and emergency rooms, regular hospital rooms may soon become obsolete. One “virtual hospital” already exists in the United States: the Virtual Care Center in St. Louis. Nurses and doctors work there and have individualized, extended interactions with patients – but there are no hospital beds to be found. All of the hospital’s patients are monitored remotely, staying either at home or in intensive care units. AI surveillance algorithms in their rooms can detect possible heart failure or sepsis and send warnings to clinicians. This virtual hospital is an anomaly today, but that may not be the case for long. AI is likely to transform not only hospitals, but other health systems as well.

The key message here is: Artificial intelligence can help reform health systems and improve scientific research.

Remote monitoring will become increasingly important as more hospitals go virtual, and similar technology can be used to support seniors. For instance, sensors embedded in a person’s floor can alert staff if they’ve fallen. Given that each night in a hospital costs an average of $4,700, anything that helps mitigate the financial burden is welcome. Today, just the cost of accurate medical billing adds a whopping 25 percent to the price of an emergency room visit. Clearly, AI could step in to cut those costs. Automation might improve efficiency and workflow at hospitals in the future, but it’s already having an impact at the lab. AI has helped scientists unlock the mysteries of the human genome. Algorithms have successfully identified 2,500 genes that contribute to or cause the symptoms associated with autism, for instance. And its usefulness doesn’t stop with just identification – AI can also be used to edit the human genome and eliminate diseases like hemophilia and sickle cell anemia. Drug discovery is another important use for AI. After all, there are far more chemical combinations possible than the number of atoms in the entire solar system! One painkiller discovery project used an algorithm to narrow a list of three million potential painkilling compounds down to just 23. So, AI can help with much of the behind-the-scenes work in health care and research. It can also benefit patients directly.

Regardless of age, all humans must take one particular type of medicine in order to survive. That medicine is food. Ever since the days of the ancient Greek doctor Hippocrates, people have believed that health and food go hand in hand. While government agencies and people in the food industry might argue they hold the key to a healthy diet, is a one-sizefits-all approach even possible? Given how biologically and physiologically different we all are, shouldn’t our diets reflect that? With the help of artificial intelligence, there may come a day when we receive individualized nutrition recommendations and other forms of personalized medicine. The key message here is: Artificial intelligence could help to personalize our medicine and our diets. Research done at the Weizmann Institute of Science in Israel reveals one way that individuals respond differently to different foods. Crunching millions of data points – including participants’ dietary habits, physical activity, and gut microbiome – a machine learning model was able to identify 137 factors that could predict people’s glycemic response. This is a measure of how high a person’s blood sugar spikes after eating a particular food. After the algorithm did its work, 26 people were given personalized diet plans tailored to their predicted glycemic response. They showed significantly improved glucose responses after eating compared with the control group. That’s important since substantial glycemic spikes have been associated with the onset of diabetes, obesity, and heart disease. Artificial intelligence like the one used in the Weizmann study can be used more broadly to provide individualized diet plans. Other aspects of our health could be similarly personalized with the development of virtual medical assistants we carry around in our pockets. Some technologies like this already exist, but they focus on specific areas. One app called Migraine Alert, for instance, uses machine learning algorithms to predict a user’s oncoming migraine with 85 percent accuracy. This allows the person to take preventative measures instead of simply treating the migraine once it’s started. Right now, the amount of data required to make a truly comprehensive virtual medical assistant is prohibitive. We’re a long way off from being able to ask our fridge, “What should I eat today?” At the moment, it may be best to focus on narrower concerns. In our final blink, we’ll look at what human doctors can do in the face of the AI revolution.

When the author entered medical school in 1975, health-care facilities and medical practices looked very different than they do today. Clinic appointments were scheduled to last a minimum of one hour for new patients and 30 minutes for returning ones. Notes from a visit were often handwritten in a person’s chart. Monthly productivity reports for doctors didn’t even exist. At that time, there were fewer than four million health-care jobs in all of the United States, and annual health-care spending totaled less than $800 per patient per year. By contrast, today, there are over 16 million health-care jobs, and spending tops $11,000 per person, per year. As health care has become more and more of an economic endeavor, the human side of care has begun to die off. Fortunately, artificial intelligence has the potential to resurrect it.

The key message here is: Automating clinical functions will allow doctors to focus on patient care.

With its potential to automate certain job functions, artificial intelligence could help free up an estimated 25 percent of doctors’ and nurses’ time. This would allow for better worklife balance for them and for longer visits with their patients. One study looked at the effects of the length of home health visits for over 60,000 patients. It found that for each additional minute a visit lasted, the risk of readmission was reduced by 8 percent. Additional time can help physicians become more “human,” but it’s not the only factor. Empathy is another. A review of 964 studies found a definitive link between a doctor’s ability to empathize and positive clinical outcomes. Today’s average medical professionals, however, receive low scores on empathy quotient tests. Fortunately, studies show that behavioral training can help foster empathy. In addition, doctors must be present. They should listen intentionally and carefully to patients, giving them their undivided attention. On average, doctors interrupt their patients just 18 seconds after the start of a visit. In doing so, they deny patients the opportunity to be heard and understood. Artificial intelligence will be able to take over tasks relying on raw intelligence, pattern recognition, or massive data synthesis. But they’ll never be able to replace the uniquely human qualities of empathy, trust, or compassion. It’s time for doctors to begin actively cultivating them.

The key message in these blinks: The medical industry is traditionally slow to adopt new technologies, but in the coming years, we’re bound to see an increased presence of AI in health systems, clinical practices, scientific research, and personalized medicine. With the time and cost savings AI can provide, doctors will be able to – and, indeed, they must – begin to focus their efforts on nurturing deep, empathetic relationships with their patients. It’s time we bring the human side back to medicine.