# Disruptive Technologies in Medicine

*The Dawn of Virtual Reality and 3-D Printing in the field of Medicine Revolutionizes the Science of Healing.*

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**Abstract**

*Since the American Civil War, the cost of battle on the human body has been forefront in the consciousness of society. Then, the disruptive technology of photography brought the horror of the aftermath of war directly to society’s collective vision. Later, following World War I, the horrific wounds sustained by troops demanded innovative treatments; facial or limb prostheses and reconstructive surgery allowed the Veterans of this war, and later wars, some return to normalcy.*

*It was the advent of computer technology, first used in mathematical calculations and eventually progressing to the pervasive status of today, which has allowed medical science to advance to levels once thought impossible. As mankind’s capacity for violence and destruction reaches levels unimaginable, so too has mankind’s ability to help and heal those who are victims of it, those born less fortunate, and those for whom there was no hope previously.*

*Computer technology has evolved to encompass many technologies ranging from communication to imaging, simulation, and is now even advancing to the point of artificial intelligence; yet it is the arrival of Virtual, Augmented, or Mixed Reality, and 3-D Printing which will shape medical science and allow it to flow forth in unanticipated ways the likes of which Hippocrates could only call divine*.

Throughout history, the technological advances of mankind have increased its ability to commit violence upon the world. As tools and techniques are developed, they are eventually adapted to warfare. The dawn of the Stone Age saw the use of crude tools for farming, hunting, and eventually killing. The discovery of creating fire, the Bronze Age, Iron Age, and beyond all saw an adaptation of innovative new technologies for violent means. Crude tools became weapons, and then the various tribes and nations invented the means to protect themselves using the same materials and technologies to create armor. But, just as humans have knowingly advanced their knowledge of killing one another, so too have they advanced their knowledge of healing. Fire created warmth, and eventually provided a means of sterilization, while the crude daggers and swords of ancient warfare evolved into precise surgical tools and the metallurgical science behind them advanced to allow for the building of the hospitals they are housed in. Even the science behind the deadliest weapons of the world is responsible for the treatment of various forms of cancer, and for powering portions of national energy infrastructures.

Disruptive technologies throughout the history of the world have caused to upheaved the traditional social, political, and military balance of power of the eras in which they were discovered. None will argue that the discovery of iron forging, and eventually the forging of steel, did anything but determine the course of the future. The same is true of the Information Age and the advances in computer technology that seem to occur almost every day. While there are several precursor devices, such as the Antikythera Mechanism, that could be considered a simple computer, the main use for computing devices was in the form of warfare, first with the Z3 designed by a German Engineer, and later by the Allies to crack the cyphers used by the Axis Powers in World War II. Yet, throughout the following decades, advances in computing technology changed the world for the better. Granted, the efficiency of killing reached an all-time high, but so had the efficiency of life saving, and life giving. From advanced imaging techniques to computer assisted surgery and colossal databases of medical information, computers are responsible for saving millions of lives. One would think that our collective societies have reached the apex of medical science, that unlocking the Human Genome is the only possible next step, but new disruptive technologies have surfaced and once again shifted the balance.

While there are many technologies that qualify, this paper will focus on only two: Virtual Reality, and 3-D Printing. **As the most recent and revolutionary technologies adapted for medical use, Virtual Reality and 3-D Printing, together, are poised to change the practice of medicine, and perhaps even upheave its scientific foundations.**

This paper makes no assumptions about the readers’ familiarity with the technologies, techniques, and terms used throughout its contents. Therefore, it is necessary to define certain terms.

Disruptive Technology, as used within this paper, is a method, technology, or technique which causes upheaval throughout the traditional foundations in one or more key areas of society, medicine, science, political affairs or military operations. Disruptive technologies often supplant the previous traditional methods, or augment them in such a way as to fundamentally change their pace and direction. Nuclear fission, and later fusion, are both examples of a disruptive technology, as is modern computing. However, throughout history other disruptive technologies have shaped the course of our lives, and our ancestors’ lives. The development of the modern world would be slower, were it not for irrigation and the water wheel. The discovery of wind propulsion, in the form of sails, allowed for cross cultural pollination and trade. The arch and its keystone were invaluable discoveries which were followed by innovations in geometry, physics, and architecture. All disruptive technologies share one common trait: they form a branch from which the course of human history, discovery, and innovation moves forward in unanticipated ways. Every innovation throughout human history was at the time of its discovery or adoption a disruptive technology.

Though not new, Virtual Reality is one such disruptive technology. Within the scope of this paper, virtual reality also encompasses the recent innovations of augmented reality and mixed reality, which will be examined in turn. So closely are they tied to the foundation of virtual reality that it is impossible to discuss innovations in the main field without also factoring the innovations of these new concepts as well.

Virtual reality is the display of graphics near the human eye by means of specialized helmet or goggle mounted equipment. This level of immersion is visually exclusive, meaning that all other outside visual stimulation is removed, and is often augmented using sounds transmitted through earphones, and recently with additional clothing worn which interacts with the computer program providing a level of physical stimulation or sensation. Other peripheral devices, such as human interaction devices in the form of simulated weaponry, or treadmills which provide the sensation of movement while running or walking, are also available, though these quickly become cost prohibitive.

Though virtual reality is only recently making headlines, it has been in use for several decades. Like many of mankind’s recent innovations, its roots are found in our imagination through literature, particularly science fiction. Aldous Huxley wrote of “the feelies” in his novel *Brave New World*, published in 1932. A form of entertainment in Huxley’s fictional world, the feelies provided an interactive reality through direct neural stimulation, allowing a person to experience the physical and mental interactions of characters viewed on a televised screen. Previous devices, which could be viewed as the forerunner of Virtual Reality, include the Stereoscope, created in 1838 by Charles Wheatstone, and the View-Master, a popular children’s toy created in 1939 by William Gruber (History of Virtual Reality, Virtual Reality Society).

Perhaps it was this novel, or any number of other science fiction stories from the era that led former Naval Radar Technician, Douglas Engelbart, to view computers in a way to transcended their use as mathematical devices to envisioning a means to accomplishing advanced display related tasks in the decade following World War II (NCSA Archives). In the 1960s, communications and computing began to intersect, and Engelbart’s vision started to take hold among the scientific computing community. Naturally, military operations took center stage with these new techniques, and an advanced radar net covering North America was created, processing data and displaying it in real time. Later, computers were used to model data used in the design of aircraft, and eventually aircraft simulators became the safest, least expensive, and most efficient means to train pilots. Though notably there were other flight simulators which predated these, they were entirely electromechanical and contained no graphical elements. Perhaps Gordon Moore was speaking specifically of computers when he made his famous prediction regarding the number of transistors on a processor, it is certain that Moore’s Law applies equally to all mechanical, electrical and computerized devices. As the complexity and capabilities of these devices increase, their respective sizes decrease. Large, cockpit style simulators are still in wide use, they are slowly pushed aside for smaller devices with helmet mounted displays relaying real time data and simulations directly to the trainee’s field of vision. (Virtual Reality: History, University of Illinois Archives).

In perhaps the prototypical example of the cyclic nature of human imagination and innovation, the old concepts introduced by science fiction wound their way through the military industrial complex, and back to their origins in entertainment. Computerized and augmented graphics found their way to movies, video games, and popular media, bringing these concepts to entirely new generations of imaginative thinkers, inviting further innovation. One of these new thinkers was Luckey Palmer, founder of Oculus in 2012, which was later acquired by Facebook in 2014 for approximately two billion dollars, (Kumparak). Oculus, and other companies following suit, brought virtual reality to the consumer. Though still in its early stages, virtual reality entertainment in the form of movies and video games is becoming commonplace, with demanding benchmarks and technical specifications creating a new level of competition among companies.

Augmented Reality differs from Virtual Reality in that it is not exclusive, but semi-inclusive of the physical world. Meaning, Augmented Reality creates an overlay of graphics in the form of data, a projection of graphical elements outside the source, or an injection of new or fictitious graphical elements. One simple example is a recently popular mobile game, Pokemon Go, which creates an overlay of fictional fantasy characters when viewed on an Internet connected wireless device’s screen, such as a modern smartphone (Malik). Another, more complex, device is the $400,000.00 helmet worn by pilots operating the F-35 Joint Strike Fighter. Using advanced imaging technology, the F-35’s helmet display is able to project a view of the environment outside the cockpit, allowing the pilot to effectively see through the skin of the aircraft, among other advanced tasks. Now, instead of relying on the gauges in the cockpit, the pilot can maintain visual contact with the outside environment, while being fully aware of the status of his or her aircraft, and other external factors impacting the mission, (Mizokami).

The next step of Virtual Reality is Mixed reality, an extension of Augmented Reality that works with the outside environment to create a highly immersive graphical interface incorporating new, or outside visual elements which work with the physical environment, allowing two or more individuals to interact with certain aspects of it. The most notable example of a Mixed Reality capable device is the HoloLens, by Microsoft. Using the techniques born from recent Virtual Reality innovations, the HoloLens projects these virtual elements onto the user’s field of vision as in Augmented Reality. How it differs however is that these new elements work with the physical landscape and incorporate seamlessly with certain aspects. While a HoloLens user may seem to be staring at a blank table, the holographic simulation they are interacting may be the three-dimensional image of a building, using the table as its foundation or street-level environment. “Mixed reality encompasses a wide range of experiences that previously were considered to be only augmented reality or only virtual reality. In mixed reality, people, places, and objects from your physical and virtual worlds merge together in a blended environment that becomes your canvas,” (Microsoft). With Mixed Reality, team members collaborating on a project can interact with the same graphical model in real time, despite a separation of distance. A battlefield commander views and directs the pace of operations, or a team of surgeons interact with a model of a patient, before or during a vital medical procedure.

It is the final example, the use of Virtual, Augmented, or Mixed Reality in patient care that qualifies it as a Disruptive Technology. In a world where the discoveries of new and incredible means of violence occur nearly every day, true innovation comes from saving lives and improving the quality of life for many that previously had no expectations, or hope. Focusing on the patient, Virtual Reality opens the door to new methods in the treatment of mental illness or conditions such as Post Traumatic Stress Disorder (PTSD), (Carson). In 1997, researchers began experimental treatments using the “Virtual Vietnam VR Scenario” for the treatment of PTSD occurring in Veterans of the Vietnam War, (Roy). This groundbreaking treatment led adaptation of the existing “ICT Full Spectrum Warrior,” (Roy), a Virtual Reality Combat Simulator used by the Department of Defense, into a platform for the assessment (through the use of extensive monitoring technologies and visual observation by professionals) of individuals potentially affected by PTSD, and further into an immersive therapy, in which the participant engages in a number of mundane tasks which may trigger a PTSD response. Once such immersive therapy may include a simulation of user walking through a crowded public location, such as retail center, with intense visual simulation coupled with physical sensations gained from having so many people close to one’s personal space. The goal of such a simulation would involve the participant to navigate the crowd from one end to the other, while maintaining steady breathing and calm heart rate, measured by medical technologies. This “gamification” of a common challenge those with PTSD face would create a positive feedback loop, in which the participant’s natural competitive tendencies drive them to control their physical responses and ultimately teach them the means to conquer them in their everyday world.

Though the use of medical cadavers has a sound scientific foundation, its practice throughout history, even in modern times, has proven morally questionable. Once entirely illegal, it is still difficult to find viable sources for vital medical or scientific research. As indicated by the Virtual Reality Society, Medical Virtual Reality opens the door for continued development of medical skill using interactive, simulated patients. The same simulation may be used through thousands of training cycles, all but eliminating the need for actual cadavers, and the creation of medical waste. Though no doubt some cadavers must form the initial basis for any simulation, this paper will cover another possible method in a later section. Besides the initial training of medical professionals, Virtual Reality simulations create the possibility of modeling a patient’s body, before surgery, which allow surgeons to practice complex techniques using the actual environment they will encounter. A virtual reality simulation of a patient suffering a gunshot or shrapnel wound would allow those attempting to remove the foreign object to see its exact placement, and even practice removing it, without adversely affecting the patient’s current state of health.

There are other important factors to consider as well. The sensory exclusion aspects of traditional virtual reality create a complex problem for the human mind, one which it rushes to understand. By introducing stimulation of the other senses of taste/smell, hearing, and the sensation of touch, an entirely new dimension of treatment emerges. In August of 2016, a study concluded at Duke University, in which researchers used Virtual Reality in the treatment of patients with complete paralysis. The most dramatic change was seen by a patient who was paralyzed for 13 years, after little more than a year of therapy using Virtual Reality the patient regained partial mobility, and was walking using “a walker, braces, and a therapist’s help,” (Khanna). Voluntary movement of her legs was achieved after this, while supported in a harness. Several patients in the Duke University study received an upgraded prognosis from complete paralysis, to partial (Khanna). For patients experiencing complete paralysis for years, even a small amount of improvement, especially in the form of partial movement, is a miracle gift with value beyond measure.

The other disruptive technology discussed here is 3-D Printing, a relatively new technique of constructing physical objects based solely on a computerized design. The history of 3D-Printing is tied closely to the development of mass production, and the evolution of synthetic materials. Previous, and still widely used, manufacturing methods involve the use of heavy machinery to cut and shape blocks of raw material, such as steel, into various component parts which are then assembled by hand or with the assistance of other automated machinery. Though lighter materials such as plastics and aluminum have largely replaced steel in many of these applications, much of the world’s manufacturing still involves expensive, finite resources creating a monopoly of interdependence between suppliers, manufacturers and consumers. Mass Production has long been the foundation of economies, particularly the economy of the United States, and all involved parties have an interest in maintaining it as such.

However, the rise of plastics and molding technologies created a new process, 3D-Printing, which challenges the traditional methods of production. Though there are a myriad of techniques and materials used, including metal in some cases, 3D-Printing uses as computer generated file as a model and commonly produces a plastic or polymer representation of the model as a finished product. The associated computer programs in 3D-Printing both render and breakdown the generated model into layers, or slices, which are then processed and passed onto the 3D-Printer. The 3D-Printer uses an extruded liquefied plastic or polymer compound to create each slice, in turn, until the entire model is complete. In all, the entire process could take several hours to several days, but is highly dependent upon the complexity and size of the model. Though injection molding and other traditional forms of manufacturing still represent the most efficient and cost effective means of producing high quantities of finished goods, 3D-Printing allows a micro level of manufacturing available to the consumer marketplace, and makes it possible to produce finished goods that were previously unavailable due to the costs of startup modeling, tooling and manufacturing. Even within the market of prosthetic limbs, most take a “one model fits all” approach, have limited options for adaptability to an individual’s needs and very costly. With 3D-Printing, a patient may create their own prosthetic, tailored to their needs, at a fraction of the cost.

Though 3D-Prining has caused significant concern with intellectual property theft, and in a few cases, the manufacture of firearms (Atherton), the use of 3D-Printing in medicine has already taken center stage. In February of 2012 surgeons at the University of Michigan’s C.S. Mott Children’s Hospital operated on a three-month old patient suffering from a condition causing his airway to periodically collapse. A three-dimensional model of the patient’s chest was created, and from there a 3D-Printer was used to create a biocompatible tube which was placed over the weakened area to hold it open. The child was reportedly healthy in May of 2013, with no adverse reactions, (Groopman).

As with Virtual Reality, the practice of medicine becomes easier using 3D-Printing technology; medical professionals may examine an authentic, and in this case physical, representation of the patient’s anatomy, or portions thereof, and familiarize themselves with the intricacies of the patient’s individual biology. Using life like printable polymers, the texture, or “feel” of a human body may be recreated; again, allowing medical professionals to practice their skills on models, rather than cadavers, or to explore methods which would create undue pain for a living patient.

Also, the application of 3D-Printed materials in the use of reconstructive surgery represents a dramatic leap forward the victims of disfigurement or those born with certain genetic defects. Using similarly biologically stable materials as those used in the University of Michigan patient, children born with malformed skeletal structures may receive an implant which helps stabilize the bone, and guide it in a manner like the method used by dental braces, Dental braces themselves may evolve from the mostly metallic dental implants in use today, to a device with a natural appearance and better suited to the patient’s comfort. Revolutionary medical devices, such as the “Total Artificial Heart” face another evolution of design, using 3D-Printers to create lower cost, and with the correct imaging technology, individualized implants, (National Institutes of Health).

The next logical step in 3D-Printing for medicine involves the leap from inorganic, but biologically neutral polymer compounds, to organic substances and perhaps even a form of living tissue. The use of cloning technology received notoriety several years ago, and has largely disappeared from the collective public mind, yet it has not ceased development. Biological cells are cultured and grown throughout laboratories worldwide, and in yet another example of the demand for human tissue, cadaver skin is used in various surgeries as a neutral substrate bandage. The leap from inorganic to organic compounds will create many challenging moral questions, but will also clear the path for medical research and innovation that will improve the quality of life for all. Now, using 3D-Printing, an amputee may receive a prosthetic at a fraction of the cost compared to acquiring it from traditional sources. In the future, an amputee may be able to receive a limb constructed from his or her own genetic material, and as such, free from the dangers of tissue rejection.

However, both Virtual Reality and 3D-Printing open the door to the possibilities of misuse. As mentioned previously, the techniques and models for both may be the intellectual property of a third party, without permission for duplication or disbursement. The pace of innovation in these technologies, and their logical leap forwards, may create an entire new system of “haves” and “have nots”, in which the consideration for treatment may not be medical necessity, but rather social or economic standing. There may be a time in which a person may be chronologically older than their peers, but physically superior or genetically younger because of these technologies, particularly if 3D-Printing makes the leap from inorganic to organic construction, or in a different direction, if allows for the creation of cybernetic augmentation. Unfortunately, some of the innovations throughout history, particularly in the medical field, have their origins in morally questionable or corrupt practices. While acknowledging their capacity for abuse, the examination of this possibility is outside the scope of this project.

Previous examples discussed the use of imaging technology to create a model of a patient, or a virtual mock-up of a patient, in which medical professionals collectively examine from diverse geographic locations. Another discussed the use of organic tissue compounds to construct a mock-up of a patient’s anatomy. In the cooperative use of both technologies, a patent may be suffering from a life-threatening condition, one which his or her local medical facilities are ill equipped to treat. Rather than transport the patient to an alternate location, one which may not even exist inside his or her home nation, the local medical professionals may receive vital assistance using collaborative Virtual Reality technologies and 3D Printing in tandem. The patient is scanned, and a three-dimensional model of their body, or affected region of their body, is constructed and uploaded to a database. Medical professionals at the specialized location are then able to review the model, and create an extensive recreation to examine the patient. This examination requires no further effort on the patient’s part, and may be faster than current methods. After the specialists complete their examination, a thorough plan of action is created. Unique physical tools are developed, or modeled and created using 3D-Printing, while mechanical, organic or biologically neutral components are also constructed and ready to replace any failing organ or limb. Again, rather than transport the patient to the specialty location, collaborative Virtual Reality technologies in the form of Mixed Reality, or holograms, project the surgical team to the patient’s location, who then guide the on-site professionals in the operation or use remotely controlled devices to perform the procedure. Yet another iteration of this same example could yield a result in which the specialists create a computerized routine, and then upload it to the patient’s location, whereupon the surgery is performed entirely by computerized and robotic equipment; although, this version produces the most dystopian prediction for these technologies. This example is but one possibility, however, and focuses on the physical, rather than the mental wellbeing of patients. Collaborative Virtual Reality technologies create new methods of treating emotional or mental stress and illness, and even 3D-Printing comes into play as a creative expression. Rather than construct a device that is meant to heal or augment the body, these technologies may form an outlet for a person’s artistic expression, creating a form of therapy often used for treatment of mental conditions.

When considered singularly, both Virtual Reality technologies and 3D-Printing stand apart as disruptive technologies, however it is extremely rare for two such technologies to not only exist concurrently, but to complement one another so thoroughly. The pace of technological innovation is drawing these two technologies closer to one another daily; it is an inevitability that they will merge into an amalgamation of revolutionary ideas. The human capacity for innovation is boundless, subject only to the limitations of an individual’s lifespan; the imagination of others born over a century ago has proven to be the inspiration for countless advances. As we progress, our advances once again spark the imagination, giving rise to fantastic stories, which are then used as the inspiration for greater advances. Virtual Reality and 3D-Printing are on the cusp of widespread adoption, and already causing a revolution of new techniques and challenges; together, they will revolutionize medical science.

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