

Future of Medical Equipment Technology

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Advances in manufacturing and digital information technology have sparked the Industrial Revolution 4.0. UDIs and 6G telemedicine networks are reshaping the future of healthcare technology as part of the Fourth Industrial Revolution (4IR), which is now underway. With the help of UDIs, device recalls and post-market surveillance may be done more accurately and efficiently, and studies using UDI data can be conducted to help doctors make better clinical decisions. The development of intelligent healthcare systems is currently a hot topic, and wireless connectivity is a critical component. The goal of the 6G vision is to transform the globe into a secure and completely linked digital society through the use of communication technologies with intelligence. Stentrode, digital pacemaker, insulin pumps and coronary intervention with drug-eluting stents are some of the new methods that will improve human life. As technology continues to evolve, so will our methods of self-care. In the future, patients will continue to seek out companies that use technological innovation in medicine to empower them to take charge of their own health. The healthcare system is evolving to become more proactive, personalised, and easy for you, which makes it easier than ever to live longer and perform better.

Keywords: Unique device identifiers (UDIs); internet of medical things (IoMT); stentrode, pacemaker; drug-eluting stents (DES); public health

I. INTRODUCTION

The modern world is undergoing the Fourth Industrial Revolution (IR 4.0), and advancements in medical field technology have shown great promise in terms of improving the overall quality of human existence (Han, 2012; Kumar, 2023; Leong, 2023a, Leong, 2020). Members of the medical fraternity must work together to keep up with technological advancements in order to avoid being left behind in today's fast-paced world. They must also use technology to give the best possible care for their patients. It is unlikely that textbooks will teach them everything they will need to know, and in order to live, they will need to think outside the box in order to keep up with the rapid advancement of medical technology in the future (Leong, 2014a; Leong, 2022b; Leong, 2023b).

II. UNIQUE DEVICE IDENTIFIERS (UDIS)

In the United States, UDIs can be utilised in the majority of high-risk (Class 3) and medium-risk (Class 2) medical devices, as well as implantable medical devices. This has been approved by the FDA (FDA-USA). UDI labels and packaging are required to display the unique code of a medical device in both human and machine-readable formats in order for the item to be considered safe. The UDIs assist in determining the manufacturing data, which includes the production batch number and manufacturing and expiration dates, among other things (Wilson, 2021). When there are unfavourable clinical reactions to surgical devices or implants, these UDIs preserve a complete record of device failures, which helps surgeons make informed judgments about future procedures.

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Furthermore, these UDIs keep a detailed record of device failures when there are unfavourable clinical reactions to surgical devices or implants, which helps doctors make smart decisions. There is no longer a need to manually clean and process data because UDIs now link clinical and device data for comparison studies of efficacy and performance. Some healthcare organisations prefer to scan their UDIs at the point of care (POC), like in cardiac catheterisation laboratories (cath labs) or operating rooms. This is because UDIs are important for clinical procedures (ORs). According to Wilson *et al.* (2021), the cath lab is the most common place to use UDIs. The operating room and interventional radiology are also common places to use UDIs (IR).

III. 6G NETWORK

Machine-to-machine (M2M) communication is a critical component of the "Internet of Things" (IoT), which enhances the connectivity of devices in the home, office, industry, and, in particular, the healthcare field. M2M communication is a key component of the "Internet of Things" (IoT). In this industry, how critical is it to have a physical link or to use wireless technologies to communicate? What kind of electrical power do these communication modules require? What is the effectiveness of these devices in terms of their range?

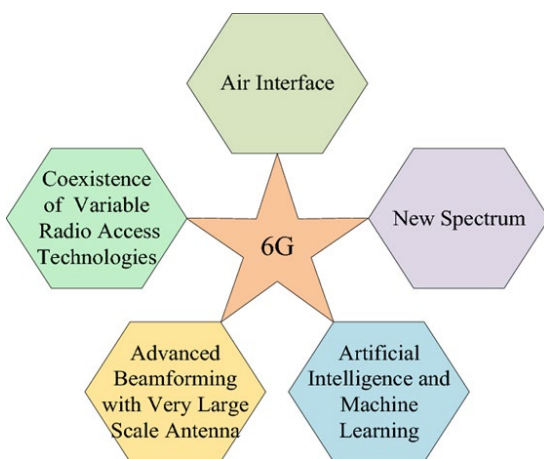


Figure 1. 6G system architecture.

A. Network Architecture

In order to accommodate the growing number of Internet of Things devices, 6G network architecture must be spectral and energy efficient, have low latency, and be widely connected. Connected drones and robots will make it feasible to automate traffic flow, monitor the environment while providing virtual navigation, provide telemedicine, conduct digital sensing and transmit higher-quality video transmission (Leong, 2014b).

B. 6G Vision for Healthcare Services

Fifth-generation (5G) wireless communication networks strive to provide a dependable, faster network that can serve thousands of devices with low latency while also being more cost-effective. The following are the recommendations made by (Janjua, 2020; Leong, 2023d) for 6G healthcare services and technologies:

- i. telepresence via holograms
- ii. tactile internet
- iii. self-driving and artificial intelligence-based vehicles
- iv. aerial networks
- v. internet of bio-nano things (IoBNT)
- vi. uncoordinated networks and co-existence of radio
- vii. frequency (RF)
- viii. communication via visible light (VLC)
- ix. terahertz (THz)

Figure 1 shows the important parts of the 6G system architecture, which will change the way the 6G standard is implemented in a big way (Janjua, 2020; Leong, 2019; Leong, 2006a; Leong, 2023c). The air interface is the key part that allows for big changes in wireless generations.

Healthcare institutions such as hospitals, distant medical facilities, and disaster response units are three of the most critical locations where the new 6G network will be put to use. Artificial intelligence will play a significant role in the decision-making process in the medical field, with the assistance of high-tech robotics that can be utilised in surgery with extreme precision (Leong, 2005; Leong, 2008). It will be possible for medical data collecting centres to receive data directly from the Internet of Things-enabled

wearable devices and sensors, as well as to monitor and transmit patient health information.

Telemedicine and remote health monitoring are currently conducted using high-quality video conferencing technology, but in the near future, hologram technology, which is also known as holographic representation, will be employed instead. This new technology will be supported by a potential 6G network in the near future. Wearables and wireless body area networks are the terms used to describe these technologies (WBANs). A disaster response unit can provide health care services in risky or emergency conditions, such as disaster management centres, emergency mobile service (EMS), field hospitals, and public space monitoring. Medical equipment that is advanced enough to be found in smart ambulances serves to expedite the process of identifying and treating patients.

The goal of 6G is to transform the world into a safe and completely connected digital society that extends beyond the confines of space. To reduce the digital gap, unmanned aerial vehicles (UAVs) and other platforms that are not based on the ground are being used. Wireless communication would become possible everywhere as a result of this development. There would be less route loss and a higher likelihood of line of sight (LOS), as well as greater flexibility.

Systems of the future will have to consider issues such as communication security and how to keep users secure. As a result, much work needs to be done to ensure that these new technologies are compatible with the healthcare system and that they can be used in real-time (Leong, 2006b; Leong, 2012).

IV. ADVANCEMENT OF MEDICAL EQUIPMENT

A. Stentrode

Using a stentrode, a medical device can be used to monitor and trigger brain activity that occurs within the body, among other things. It can be attached to the brain or to the surface of the body. The phrase "neural implants" refers to a specific type of implant that communicates with the brain via electrical signals. It is possible to insert these electrodes, which look like stents, into the body since they are made of silicon nano-electronic threads (Bhatt, 2020). As soon as

these compounds are consumed, they turn into a liquid that hardens and takes on the appearance of taffy. It is possible to wirelessly collect and record neuronal activity in a clinical database. The mesh tube, which measures 3 centimetres in length and 3 mm in width, is made from a nickel alloy known as nitinol. Its net-like surface contains electrodes, each of which can record the activity of around 10,000 neurons when they are placed on it.

B. Cardiac Pacemaker

Hyman's "artificial pacemaker" (electrical stimulation of the heart to force it to alter or beat) was the first device to pace the heart, and it was introduced in the 1930s. A direct current generator, driven by an electric current created by a manual crank, transmits electrical impulses to the patient's right atrium through an intercostal needle electrode placed in the patient's chest (Mulpuru *et al.*, 2017). The core system of pacemaker technology has not changed: an extravascular pulse generator is coupled to one or more leads that pass via the venous system to reach cardiac tissue. It progressed from massive, externally driven alternating current devices to "wearable" transistorised battery-powered pacemakers, both of which were developed during the age of external devices. There are already leadless pacemakers that can be utilised in the clinic that can be found online here. This is a novel approach to problem-solving that is receiving widespread attention (Leong, 2022a).

A pacemaker system is formed of a hermetically sealed container that contains the battery and circuitry in order to keep the battery and all of the electronics in the pre-pectoral region of the body safe. A pacemaker system can be found in the pre-pectoral region of the body. In order to connect the pacemaker to the cells of the heart, a pacemaker lead is used. A conductor coil connects the leads to the electrodes, which are separated by an insulating material that acts as a conductor between the two electrodes. Depending on how the conductor coils have been built out, either a coaxial lead (a coil within another coil) or a coradial lead (coils adjacent to each other) is used. Active fixation mechanisms or tines that pierce the cardiac structures (trabeculations) are used to attach the lead tips to the myocardial (passive fixation).

Recent advancements in cardiac pacemakers are mostly focused on three aspects, which are as follows:

- i. Resynchronise and optimise the heart's efficiency.
- ii. To prevent lead failure, valve damage and device infection.
- iii. Remove batteries and other hardware.

Battery-free pacemakers that get their power from heart movement or that change or add cells to make biological pacing is being worked on right now.

C. Cochlear Implant

A cochlear implant is a small, complicated electronic device (Figure 2) that can assist someone who is profoundly deaf or has severe hearing loss in regaining their sense of sound. In 1963, Zöllner and Keidel devised the fundamental concepts of intracochlear multichannel stimulation with up to twenty electrode connections in the scala tympani with the purpose of the simulating tonotopy through the use of several stimulus modalities (Lenarz, 2017; Leong, 2005). Advancements in electrode technology will be used to make electrode-nerve interfaces better in the future (Figure 3).

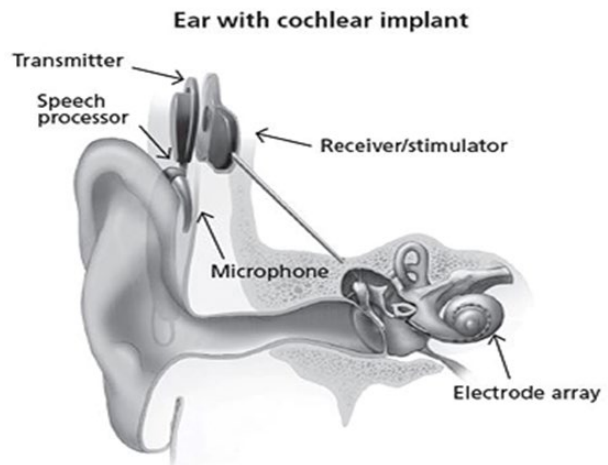


Figure 2. Cochlear implant (Bhat, 2020).

The greater the number of electrical connections, as well as the biological therapy that includes regeneration of the dendrites that form on the electrode, the greater the number of electrical channels that will be available. This will allow for improved methods of coding speech, which will allow us to create the bionic ear, which is to say, we will be able to restore hearing function through the use of technology (Figure 3).

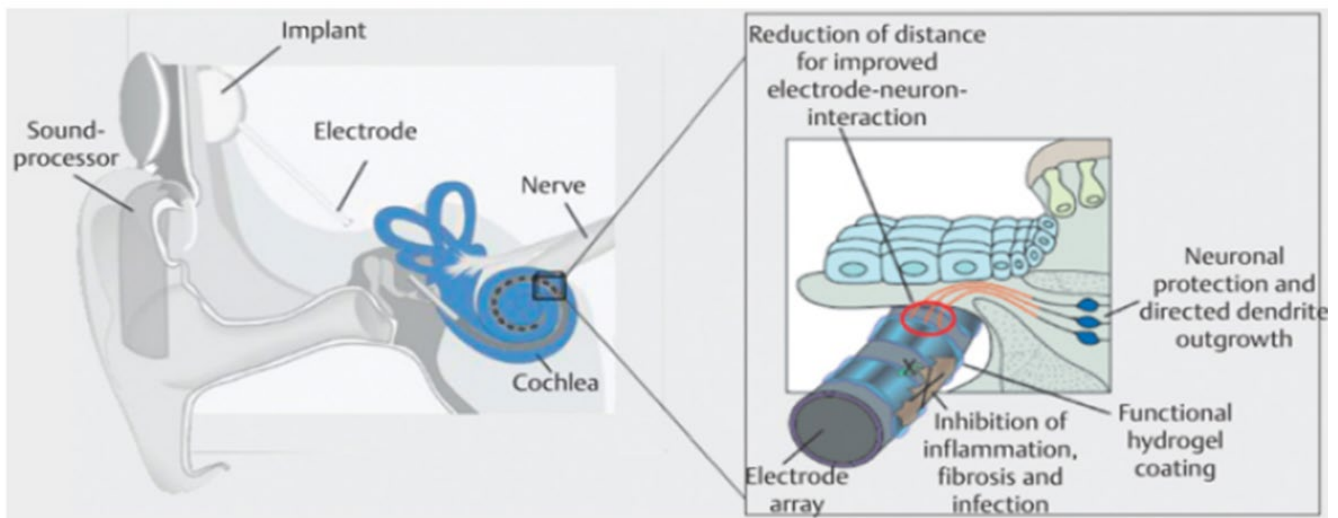


Figure 3. Future developments (Lenarz, 2017).

D. Insulin Pump

Insulin pump therapy, commonly known as continuous subcutaneous insulin infusion (CSII) therapy, is a rapidly growing technique of insulin delivery. It has been shown to be extremely effective at maintaining stable blood sugar

levels and enabling persons with diabetes to live more freely. Insulin pumps come in different sizes and shapes, but the basic setup is the same for most of them. It has an insulin cartridge called a "reservoir," which is what the pump is called. As shown in Figure 4, the reservoir pump is attached to an insulin delivery line, which in turn is connected to a

subcutaneous cannula that delivers insulin to the patient's body. Every three days, the reservoir, delivery line, and cannula should be changed. As with injectable insulin, the patient should change the place where the cannula is inserted every time.

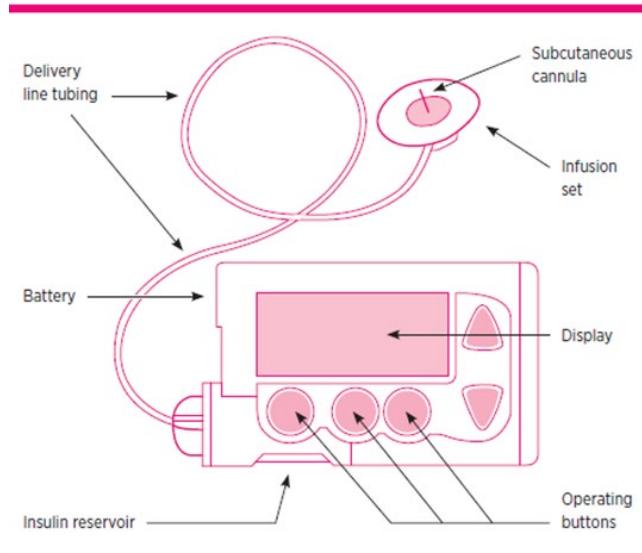


Figure 4. Components of Insulin Pump (Lenarz, 2017).

The four main settings that need to be set up in an insulin pump are:

- basal dosing,
- bolus dosing,
- blood glucose correction settings
- time for insulin to work.

There are a lot of advantages to using an insulin pump instead of a lot of injections every day. However, it is important to keep in mind that there may also be some drawbacks to this. The following are some of the advantages of insulin pumps:

- i. It delivers insulin in a manner that more closely resembles normal pancreatic function.
- ii. This method simply uses rapid-acting insulin and reduces glucose peaks and absorption-related fluctuation to a bare minimum.

- iii. Bolus algorithms are pre-installed, and they recommend bolus doses based on the user's estimated carbohydrate content and blood glucose levels.
- iv. The ability to be more flexible with day-to-day activities such as exercise, mealtimes, travel and shift work.
- v. With the integration of glucose monitoring, it is possible to obtain real-time glucose information.

However, the drawbacks are,

- i. An external device that is attached to the body at all times.
- ii. Mechanical malfunction, such as blockage or kinking in the injection set, has the potential to cause diabetic ketoacidosis (high blood sugar levels in the blood).
- iii. The possibility of insertion site complications, such as skin infections or local discomfort.
- iv. Uninsured patients face high costs and limited access as a result of this.
- v. Patients must be willing and capable of using and managing the technology.

E. Coronary Stent

According to Byrne, Stone, Ormiston, and Kastrati, Andreas Gruntzig performed the world's first coronary angioplasty procedure in 1977. (Mulpuru, 2017). Coronary stents were first introduced to the public in the mid-1980s. Throughout the years, they have evolved significantly in both design and substance, and percutaneous coronary intervention has become one of the most prevalent medical procedures performed on a global scale. Angioplasty technologies have progressed significantly over time, and this has enabled a significant portion of this advancement. A "paradigm shift" in the treatment of cardiac disease has been referred to as the introduction of drug-eluting stents (DES). This is due to the way in which these devices work (CADs). On the surface of the stent, it is possible that pharmaceutical chemicals will be released. This was a significant advancement in the field of cardiovascular stents.

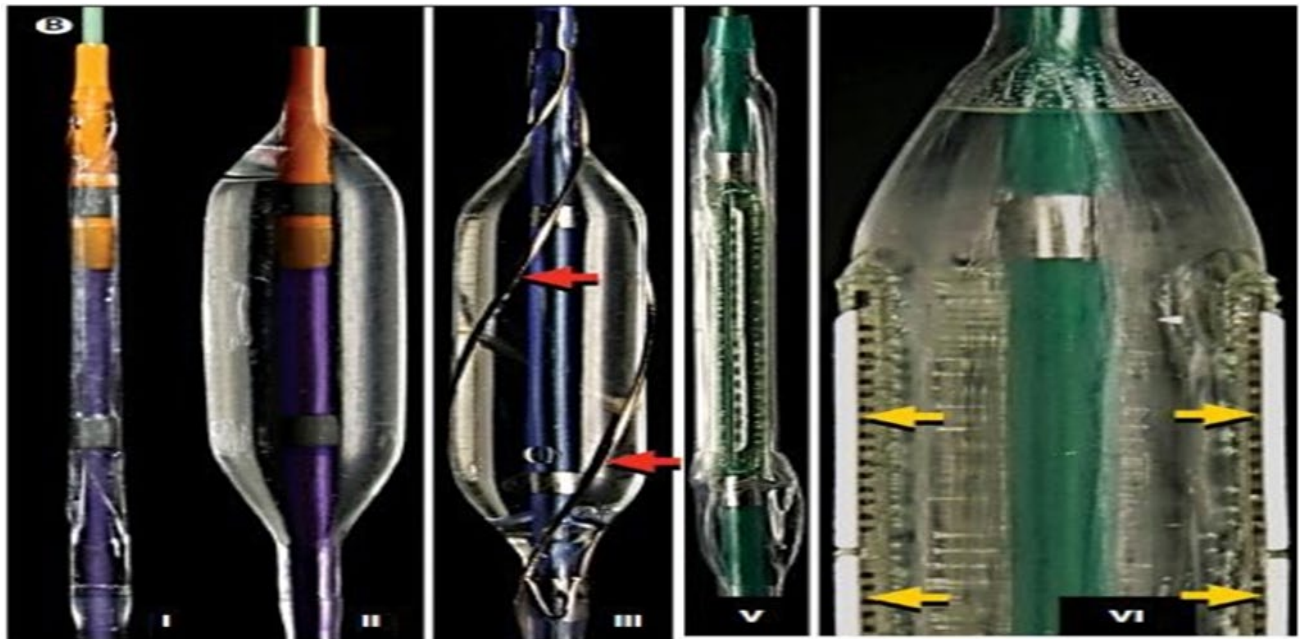


Figure 5. High-resolution photographs of a selection of balloon angioplasty catheters before and after inflation. A coronary angioplasty balloons before (I) and after (II) inflation. A scoring-balloon catheter with helical nitinol scoring elements (Red arrows) in low-power (III) magnification. A cutting balloon catheter before (v) and after (vi) inflation.

First-generation DESs were composed of three key components: a permanent metallic platform (typically stainless steel), a persistent polymeric coating on the platform, and an active pharmacological substance embedded inside the polymeric coating (that was eluted from the polymeric layer). In the beginning, DESs were a successful approach to reducing the number of times people had to undergo surgery. Antiproliferative or immunosuppressive medications were released at the site of vascular injury, which resulted in the death of the cells (Iqbal, 2013). Using shape-memory stents, for example, could be used to predict future developments in the cardiovascular field. In an ideal situation, it would have the ability to self-expand within the range of body temperature. SMPs (stimulus-responsive materials) are materials that alter shape in response to an external input. They exhibit a two-phase form transition, with the polymer fixed in a transitory shape during the first phase. In the second phase, an external stimulation stimulates the polymer to return to its permanent shape. Despite the fact that endovascular stents have revolutionised interventional cardiology in terms of clinical outcomes, stent-related complications have remained a major concern. To circumvent these limits, several articles have been presented as the preferred

treatment option for stent design. The following therapies have been documented and can be classified into one of several categories: Surface properties can be improved by using better polymer coating materials, nanocomposite materials, and a tissue engineering process. Although published evidence has not yet verified any outperformance above that expected with existing DES, bioresorbable devices must display a demonstrable clinical advantage over DES. Biomolecule-decorated polymeric surfaces paired with nano-devised procedures would be the most frequent option for future applications.

V. CHALLENGES OF FUTURE MEDICAL EQUIPMENT TECHNOLOGY

The future of medical equipment technology holds great promise, but it also comes with several challenges. Some of the key challenges include:

- 1) **Interoperability:** As medical equipment becomes more advanced, ensuring that different devices can communicate and share data seamlessly becomes crucial. Interoperability issues can hinder the effectiveness of integrated healthcare systems and lead to difficulties in exchanging information between devices and electronic health records (Mehrotra, 2009; Mohankumar, 2016a).

2) **Cybersecurity:** With the increasing connectivity of medical devices and the adoption of digital health technologies, the risk of cybersecurity threats rises. Protecting patient data, ensuring the integrity of medical equipment, and preventing unauthorised access are critical concerns in the future of medical technology.

3) **Data Privacy and Ethics:** As more health data is collected and shared, maintaining patient privacy becomes a significant challenge. Striking the right balance between utilising patient data for research and ensuring individual privacy rights is an ongoing ethical concern (Tee, 2018).

4) **Regulatory Compliance:** The regulatory landscape for medical devices is continually evolving. Navigating and complying with various national and international regulations can be challenging for companies developing and implementing new medical technologies. Ensuring that devices meet safety and efficacy standards is crucial for patient safety and regulatory approval (Wang, 2009; Wang, 2010).

5) **Cost:** Advanced medical equipment often comes with a high price tag. Affordability and accessibility are critical factors, especially in healthcare systems that may have limited resources. Striking a balance between technological innovation and cost-effectiveness is essential to ensure widespread adoption.

6) **Training and Education:** Healthcare professionals need to be adequately trained to use and interpret data from sophisticated medical technologies. Continuous training programs are necessary to keep healthcare providers updated on the latest technologies and best practices.

7) **Integration with Healthcare Systems:** Integrating new technologies into existing healthcare systems can be complex. Compatibility issues, resistance to change, and the need for seamless integration with electronic health records are challenges that need to be addressed for effective adoption (Mohankumar, 2016b; Mohankumar, 2017).

8) **Patient Acceptance and Adoption:** Patients may hesitate to embrace new medical technologies due to concerns about privacy, trust, or a lack of understanding. Ensuring patient education and involvement in the adoption process is crucial for the success of new medical equipment technologies (Mohankumar, 2014).

9) **Global Disparities:** There is a risk that advanced medical technologies may exacerbate global healthcare disparities. Ensuring that these technologies are accessible and affordable globally is a challenge, especially in resource-limited settings.

10) **Long-Term Sustainability:** Ensuring the long-term sustainability of medical equipment, both in terms of environmental impact and ongoing support, is an emerging concern. Developing technologies with a focus on sustainability and reducing electronic waste is important for the future.

Addressing these challenges requires collaboration between technology developers, healthcare professionals, regulators, and other stakeholders to create a robust and ethical framework for the future of medical equipment technology.

VI. DISCUSSION

These technologies are still in the early stages of discussion, development, and standardisation, and they are being tested in clinical settings in a number of health centres across the world. Because it is a matter of human life at stake, there are numerous obstacles that must be addressed before these technologies can be used on a large basis. Before making any therapeutic judgments involving new technologies in the medical profession, it is necessary to examine ethical and moral considerations. Problems must be resolved in order for real-time implementation to be successful and without causing any harm.

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