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Potential of Internet of Medical Things (IoMT) applications in building a smart healthcare system: A systematic review

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ABSTRACT

Sudden spurting of Corona virus disease (COVID-19) has put the whole healthcare system on high alert. Internet of Medical Things (IoMT) has eased the situation to a great extent, also COVID-19 has motivated scientists to make new 'Smart' healthcare system focusing towards early diagnosis, prevention of spread, education and treatment and facilitate living in the new normal. This review aims to identify the role of IoMT applications in improving healthcare system and to analyze the status of research demonstrating effectiveness of IoMT benefits to the patient and healthcare system along with a brief insight into technologies supplementing IoMT and challenges faced in developing a smart healthcare system.

An internet-based search in PUBMED, Google Scholar and IEEE Library for english language publications using relevant terms resulted in 987 articles. After screening title, abstract, and content related to IoMT in healthcare and excluding duplicate articles, 135 articles published in journal with impact factor $\geq$1 were eligible for inclusion. Also relevant articles from the references of the selected articles were considered.

The habituation of IoMT and related technology has resolved several difficulties using remote monitoring, telemedicine, robotics, sensors etc. However mass adoption seems challenging due to factors like privacy and security of data, management of large amount of data, scalability and upgradation etc. Although ample knowledge has been compiled and exchanged, this structured systematic review will help the healthcare practitioners, policymakers/decision makers, scientists and researchers to gauge the applicability of IoMT in healthcare more efficiently.

1. Introduction

The Internet of Things (IoT) literally means interconnected network of physical objects or 'Things' integrated to exchange data between devices/systems using internet. Since its first mention by Ashton in 1999 an exponential growth has been witnessed leading to approximately 10 billion connected IoT devices at present with a predicted increase to about 25 billion till 2025.[1,2] Technically, it involves optimization of the data exchange and storage of the information on a secure cloud server from where interconnected computing devices forms a network to share data and communicate across the server. Multiple inventions done on products/devices to make them "smart" with embedded software that either update their existing functionality with new features or enables newer functions/applications. During COVID-19 pandemic, continuous monitoring of health condition in unexpected huge number of patients during both pre and post infection stage is considerably indispensable. Internet of Medical Things (IoMT) enabled remote patient monitoring, screening and treatment via telehealth have been successfully adapted by both care givers or health providers and patients. IoMT based Smart devices are making an impact at a skyrocketing pace ubiquitously particularly in the global pandemic state. However considering the vast magnitude of need, healthcare is foreseen as the most challenging areas for IoMT.

This structured systematic review intends to identify the pivotal role of IoMT applications in improving healthcare system and to analyze the status of research implementations demonstrating effectiveness of IoMT benefits to the patient and healthcare system along with a brief insight into the technologies supplementing IoMT and challenges faced in

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developing a smart healthcare system. The first section describes the different layers, their role and workflow in IoMT. The second section unveils the different technologies that integrate with IoMT to facilitate healthcare delivery in modern times. The third section describes applications of IoMT in Healthcare. The last section enumerates the challenges faced in wide-scale employment of IoMT and finally a crisp conclusion of the overall discussion is presented.

2. Method of data collection

"An exhaustive internet based literature search following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines was carried out in PUBMED, Google Scholar and IEEE Library using search string ((((internet of things [Title/Abstract]) OR (iot [Title/Abstract])) OR (iomt[Title/Abstract])) OR (iodt[Title/Abstract])) AND (healthcare[Title/Abstract]). Only articles in english language with atleast 1 citation, published in journal with impact factor ≥1 (according to Journal Citation Reports), from publication year 2005–2020 (15 years), having relevance to the context (content related to IoMT in healthcare) and availability of full text were considered.

After initial search on the basis of inclusion criteria, 1987 articles were yielded and after filtering by title and abstract and excluding duplicate articles and considering availability of full text, total 135 articles were found. Additionally, relevant articles from the references of the selected articles were considered for this systematic review.

Fig. 1 depicts PRISMA flowchart exhibiting the search, screening and inclusion criteria."

3. HOW IoMT works!

The integration and habitation of internet into our environment has paved the path for IoMT applications and systems into our lives on a daily basis.

Most of the IoMT systems work in the following main layers that integrate different technologies, devices, sensors and systems interconnected via electrical– electronic and wired or wireless connection.[3,4] The structure and functionality of each layer is described in Fig. 2.

3.1. Perception layer - Sensor systems for data collection

The lowest strata of IoMT designated as perception layer comprises data sources like smart objects, health monitoring devices, mobile apps that are integrated with sensors like infrared sensors, medical sensors, smart device sensors, radio frequency identification (RFID) cameras and global positioning system (GPS). The sensing systems perceive change in an environment and recognize object, location, demographics, magnitude etc and convert the information into digital signals with the help of robust, wired or wireless network transmission infrastructure that act as high performance transport medium. These can also memorize and store the data for future reference.[5]

3.2. Gateway layer

As mentioned above the sensors require connectivity to the gateway established via networks communicating and storing information either locally or centrally. The communication can be over varied frequencies and can be either short range like RFID, wireless sensor networks, Bluetooth, Zigbee, low-power Wi-Fi, and mobile communications or long range like cloud computing, block chain etc.

Networks can be either Personal Area Network (PAN) like ZigBee, Bluetooth and Ultra Wideband (UWB) or Local Area Network (LAN), Ethernet and Wi-Fi connection. Also Wide Area Network (WAN) such as global system for mobile communication (GSM) that do not require connectivity, but employ backend servers/applications and wireless sensor networks (WSNs) having capability to accommodate a large number of sensor nodes, helpful in some sensors requiring low power and low data rate connectivity can be used. High-frequency fourth-generation (4G) and evolving fifth generation (5G) cellular networks are also becoming quite popular since they are reliable in connecting multitude of devices simultaneously. The colossal communication potential can boost the growth of IoMT applications for health care.'[6] and emerge as its major driver.

Different types of gateways are described below-

a) Radio-Frequency Identification (RFID)

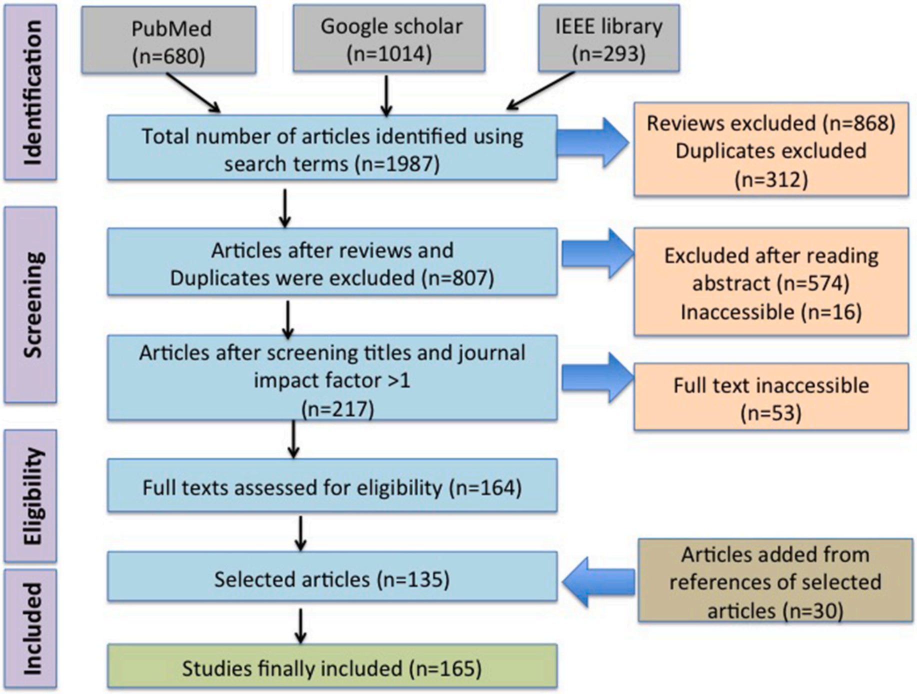

Fig. 1. Prisma Flow chart.

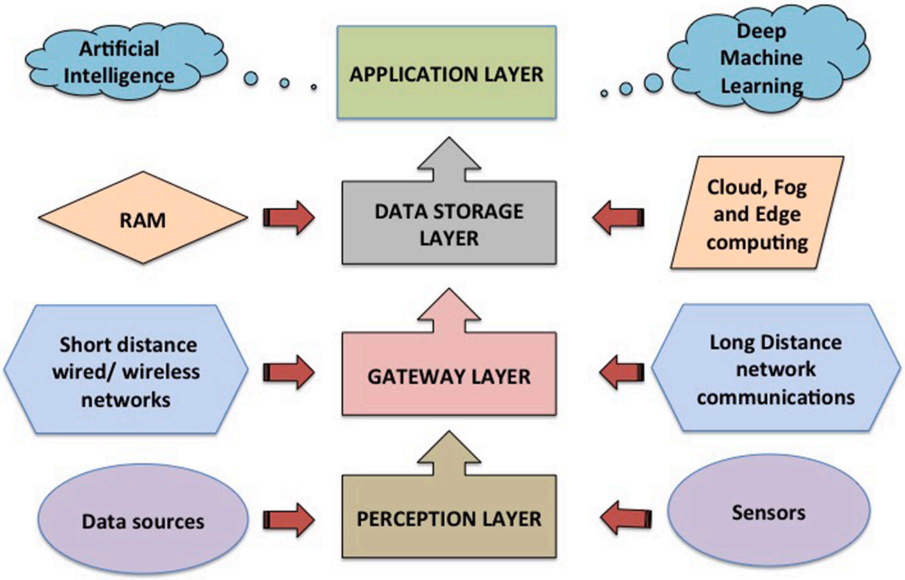

Fig. 2. Different layers involved in IoMT Framework.

This short-range (10 cm–200 m) communication gateway tag has microchip and antenna capable of identifying a specific device present in the environment and a reader that uses radio waves to communicate with the tag and transmit or receive information/data as electronic product code (EPC). RFID does not require any external power source, but it is highly insecure and may not be compatible with all types of smartphones.

b) Bluetooth

Bluetooth is a short-distance (within a range of 100 m) wireless communication technology between two or more devices employing UHF (ultra-high frequency ≈2.4 GHz) radio waves to establish an authenticated, encrypted and low interference connection for protected data transmission. It is energy efficient and cost efficacious, however this technology fails to serve in devices requiring long-range communications.

c) *Zigbee-*

Zigbee possesses a mesh network topology for interconnected, uninterrupted connection among medical devices for transmission of data. It ensures that data transmission ensues even when some of the devices are not working adequately. The frequency range of Zigbee resembles Bluetooth (2.4 GHz), however the communication range is much higher than that of Bluetooth devices. It comprises routers, end nodes and processing center that enable data analysis and aggregation. Zigbee is power efficient with high transmission rate and network capacity.

d) *Near-Field Communication (NFC)-*

NFC is an efficient, easily operable very short range communication gateway, with electromagnetic induction between the two-loop antennas placed in approximation to each other. Depending upon usage of devices for electromagnetic induction, it operates in two modes: active and passive. In active mode, there is simultaneous production of radiofrequency and transmission of data without pairing, while in passive mode radiofrequency is generated by only one device and the other device becomes the receiver.

e) Wireless Fidelity (Wi Fi)

Wi-Fi is a wireless local area network (WLAN) that has a higher transmission range (within 70 ft). It follows the IEEE 802.11 standard and is a common gateway mode employed in hospitals due to rapid and efficient network building capacity, enhanced smart phone compatibility and provision to support vigorous control and security. However, a relatively higher power usage and inconsistency of the network are the main limiting factors.

f) *Satellite-*

Satellite communication is helpful in remote geographical areas where other modes of communication are unable to function. The satellite can amplify the signals received from land and resend them. There are about 2000 satellites orbiting the Earth that enable high-speed data transfer and instant access to the broadband. Although the satellite communication technology is compatible but enormous power consumption becomes the limiting factor.[7,8]

3.3. Management service layer/application support layer- data storage

Processing of massive raw data to extract relevant information requires tools forming the management service or **application** support layer that can work at a rapid pace using analytics, security controls, process modeling and management of devices. This management/application layer provides user management, data management and data analysis.

Memory analytics aids to cache large volumes of data in random access memory (RAM) format in order to reduce the time for data query and fasten decision-making. Streaming analytics comprise of data analysis in real time or data-in-motion to facilitate fast decisions. Web servers and their gateways like Apache 2, Flask (Python Web Server Gateway Interface) provides scalability and flexibility. Databases like MongoDB (NoSQL database) provide flexibility in the variety and types of stored data. For secure communication, Secure Sockets Layer Application Programming Interface (SSL API) is employed.

The communicated data can be stored locally/decentralized (fog or edge) or centrally in a cloud server. The centralized Cloud-based computing is scopic yet flexible and scalable. It supports acquisition of data like intensive electronic medical records (EMRs) from patient portals, IoMT devices and smartphone apps stores and transmits them to the cloud for supporting decision making of therapeutic strategies'[9]

However, issues like excessive data accumulation, security, reliability, transparency and latency of health data due to distance between the devices and data centers might upsurge with centralized cloud storage in future.

To overcome this, decentralized approach 'edge cloud' is being researched upon for networking and processing of data. This allows analysis and processing of the data by IoMT sensors and network gateways themselves (ie, at the *edge*). It thereby improves the scalability of IoMT device and reduces the load of data for centralized location. Another decentralized approach 'block-chain storage' is devised that creates individual sets of information known as blocks that have a dependent but specific link. This creates a network regulated by patients rather than a third party.

Use of Edge cloud and block chain in the health care sector is still in infancy but is becoming an emerging area for research in future.[10,11]

3.4. Application/service layer

The main function of application layer is interpretation of the data and delivery of application-specific service. The application layer employs Artificial Intelligence (AI) and Deep machine learning to comprehend the EMR data and to monitor trends and changes in the collected data (contextualization of data) via different daily/weekly plots to generate decision about diagnosis and/or treatment possibilities.

The various scientific applications apart from image analysis, text recognition and language processing include health care applications like drug activity designing, prediction of risk and gene mutation expression, medical outcomes, propose management in diabetes and mental health, and predict the progression of congestive heart failure, cardiac arrhythmia, bone disease, Alzheimer disease and benign and malignant tumor.[11–16]

4. IoMT: A BOON IN healthcare

The two main drivers for fuelling an unprecedented growth in the manufacture and usage of medical devices particularly remote healthcare monitoring devices are a) Sedentary life style and oversaturated work schedules related disorders and b) Continued technical advancements in healthcare monitoring devices aiming to provide high-quality patient care at a fast pace.

Many IoMT developments, patents, and healthcare solutions might benefit the healthcare systems.[17–19] The sudden encroachment of COVID-19 has enforced accountable changes in the activities, and priorities of individuals and regulatory policies, functioning and focus of the government of nearly all countries across the globe and has been catalytic for technological, innovation and digital transformation exemplified in expanded use of digital technology for remote monitoring, telehealth and self-health assessments via smart wearables.[20,21]

In the Wake of COVID-19, regulatory bodies like U.S Food and Drug Administration (FDA) issued fast track approvals and Emergency Use Authorization certificate to several devices for handling COVID 19 complications. For instance, Whoop Strap for measuring respiratory rate, disposable patches and biosensors by Philips to detect COVID-19, Scripp's 'DETECT' that can collect data from smart wearable devices, testing and tracing architecture devised by Taiwan, Eko's electrocardiogram low ejection fraction tool for assessment of cardiac complications associated with COVID-19, 'Lumify' (a portable ultrasound device) and other hand-held portable ultrasound solutions, AI-CT algorithms for COVID-19 detection by Aidoc Medical (An Israeli technology company).[22–24] The revenue from IoMT sector has been estimated to about $66 billion in 2020 demonstrating an increase of 20% from that in 2019 owing to accelerated adoption of IoMT in healthcare sector.[25]

In the healthcare sector, IoMT has numerous applications out of which Remote/self health monitoring of various vital functions such as heart rate, skin temperature, movement monitoring[26] and monitoring of general health conditions, nutrition status and rehabilitation of elderly or infected patients are more significant leading to an increase in life expectancy and decrease in morbidity and mortality.[27]

A Smart hospital information system has been developed where various devices like MRI/CT can be linked with laboratory data to allow improved identification of medical emergencies thereby facilitating medical staff in monitoring and taking appropriate decisions for the treatment. It is notable that by making the hospitals 'smart' equipment costs could also be reduced due to the early detection of abnormalities that could affect the accuracy of specific readings from the medical devices that could otherwise lead to higher maintenance costs.[28]

Dentistry has also benefitted from the upsurge of IoMT based 'smart' technology. Newer advancements are aiming to pace up the work of the dentist along with comfort and assurance of reliability of the process to the patient. The penetration of artificial intelligence algorithms, machine learning techniques, big data analytics and cloud computing is on its path to transform dental practice.

IoMT in dentistry has several currently used as well as proposed applications which may become a common scenario in near future. As the importance of remote care swelled during the pandemic, teledentistry graduated a level up. For instance, MouthWatch's TeleDent service provides a compact tele-dentistry platform allowing patients to click images and forward the relevant information to remotely based dentist for live consultation.

In the field of Oncology, machine learning have been developed to quantify immune cells in the vicinity of oral cancer cells with precision so as to provide better insights about spread, and resistance facilitating determination of prognosis.

5. Technologies integrated with IoMT to build smart healthcare system during COVID-19

5.1. Virtual reality (VR), Mixed reality (MR) and augmented reality (AR)

The potential applications of Virtual, Mixed and Augmented Reality can be categorized into −1) Clinical/therapeutic, 2), Entertainment, 3) Business/industry, and 4) Education/training. Virtual reality (VR) technology provides a three-dimensional enticing multisensory environment to creating a sense of "presence" by modified reality experiences. Therapeutic virtual reality users wear a head-mounted display (HMD) with a close-proximity screen that provide a 'transported to three-dimensional life-like world' feeling. VR works through an amalgamation of distraction, extinction learning, cognitive-behavioral principles, gate-control theory, and spotlight theory of attention. VR has been applied in mental health and anxiety disorders, stroke and pain management, obesity management and prevention. VR aids as a supporting tool for treatment monitoring in cancer patients by influencing psychological and physiological functions. They curtail psychological symptoms related to cancer and thereby facilitate emotional well-being of the patient.[29] Yahara et al., 2021 described immersive VR induced remote reminiscence could reduce anxiety in patients with mild cognitive impairment.[30] VR can be useful in providing palliative care and reducing the negative effects of the current pandemic via video calls and simulation of the real-togetherness feel of people without traveling. In Augmented reality, superimposed computer images manipulate the users' view of the real world.[31,32] Apart from being a useful training tool AR can prove beneficial by aiding in visualization of invisible concepts and annotation by navigation in the virtual world.[33]

XR-Health developed a tele-health VR system to reduce stress and anxiety of quarantined patients to make them engaged in both physical and cognitive exercises. 'Engage' platform was developed by 'Immersive VR Education Company' for VR training and collaboration. 'EON Reality developed a VR/AR platform for industries, schools and governments for use in quarantine conditions.[34] A VR environment was also developed to study the structure, molecular dynamics, enzymes and proteins of

COVID-19 virus. Fundamental VR provides simulator-like training for surgeons where rehearsal and practice could be done for improvement of surgical techniques in a controlled environment for eg. haptic elements for tactile perception. XVision Augmedics added a 3D representation to facilitate X-ray vision like effect to visualize patient's anatomy with an accuracy rate of 98.9% when surgeons placed spinal screws in cadavers. Oxford VR is for alleviation of fear and symptoms associated with mental disorders.[35,36]

5.2. Parallel computing-fog, edge and cloud computing

Parallel processing techniques form the basis for distributed computing techniques involving paradigms like grid computing, cloud computing, fog and edge computing. IoMT and its applications that involve real-time interactions are an emerging source of big data and therefore determination and segregation of data that needs to be maintained locally from the one that has to be shared across the cloud servers becomes crucial.

The data processing architecture for IoMT systems has moved from centralized cloud computing to distributed fog computing technology.

Fog computing creates a hierarchy of layers between the hardware components and the Cloud server (core level). It reduces the amount of data stored across the cloud servers thereby reducing the network bandwidth and response time in cloud computing subsequently minimizing internet and network latencies. Fog computing also enhances data security since the data stays locally on the edge and not in cloud space.

Edge computing instead of placing the data in the cloud, maintains the data near the network edge of the device itself or by the localized server where the data was generated. Edge computing (edge level) minimizes latencies by accelerating streaming of data while processing real-time IoMT data and provides instant response to smart devices. Considering impending threats to data integrity and security in the cloud, fog and edge computing have emerged as secure and robust paradigms (Fig. 3).

Ahanger et al. developed IoMT-fog-cloud-based healthcare system for monitoring and predicting COVID-19 outspread, which included a four-level architecture-Data Collection, Information Classification, Mining and Extraction, and Prediction and Decision Modeling. They observed fog based paradigm outcomes in terms of classification efficiency, prediction viability, and reliability were markedly improved.[37]

Pham et al. developed cloud based smart home environment (CoSHE)" for efficient monitoring and health assessment at home, that comprised of home setup, infrastructure of private cloud, wearable unit and home service robot; and provided contextual information processed along with sensor data by gateway of smart home, further processed to private cloud, and provide access of recorded data to caregivers.[38] Cui et al. (2021) developed a health-monitoring framework employing cloud computing, IoMT devices, connected sensors to monitor cardiac speed, oxygen saturation percentage, body temperature, and patient's eye movement.[39]

5.3. 5G networking

Rapid development and popularity of IoMT based applications have led to evolution of fifth generation (5G) network. Recent 5G technologies comprises of new Radio Access Technology (RAT), antenna improvements, use of higher frequencies, and rearchitectured networks.

Technically, 5G is not a solitary entity but amalgamation of IoMT, big data, cloud computing, and artificial intelligence. The 5G-IoMT architecture is end-to-end coordinated and has sharp, automated and intelligent operations during each phase.[6,40] 5G enabled IoMT applications provide online reproducible information on demand and in real-time. The beneficial characteristics of 5G technologies have been depicted in Fig. 4.

5G is powerful enough to support thousands of medical devices simultaneously, from sensors to mobiles, medical equipment, and video cameras and VR/AR. Maturing 5G technologies exemplify in the form of tele-consultation, telemedicine, intelligence medicine and even remote surgery.[41,42] (Fig. 5).

Guo et al., 2021 developed a 5G-enabled fluorescence sensor for quantitative detection of spike protein and nucleo-capsid protein of COVID-19 virus.[43] Wong et al., 2020, proposed a 5G-based wireless sensor networks having fast 3 tier high security authentication scheme

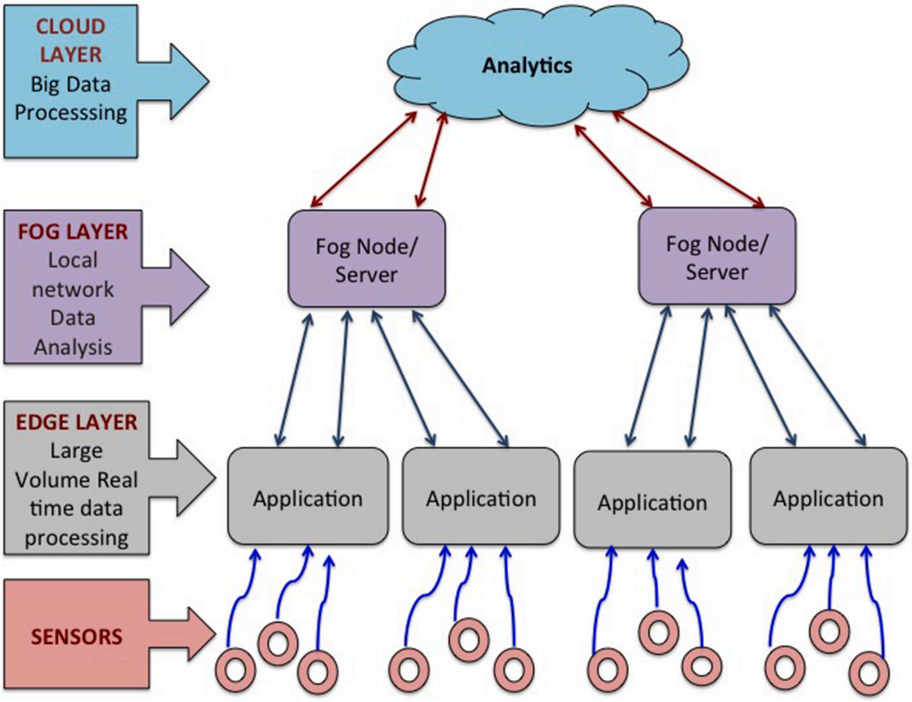

Fig. 3. Data processing Layer stacks of IoMT.

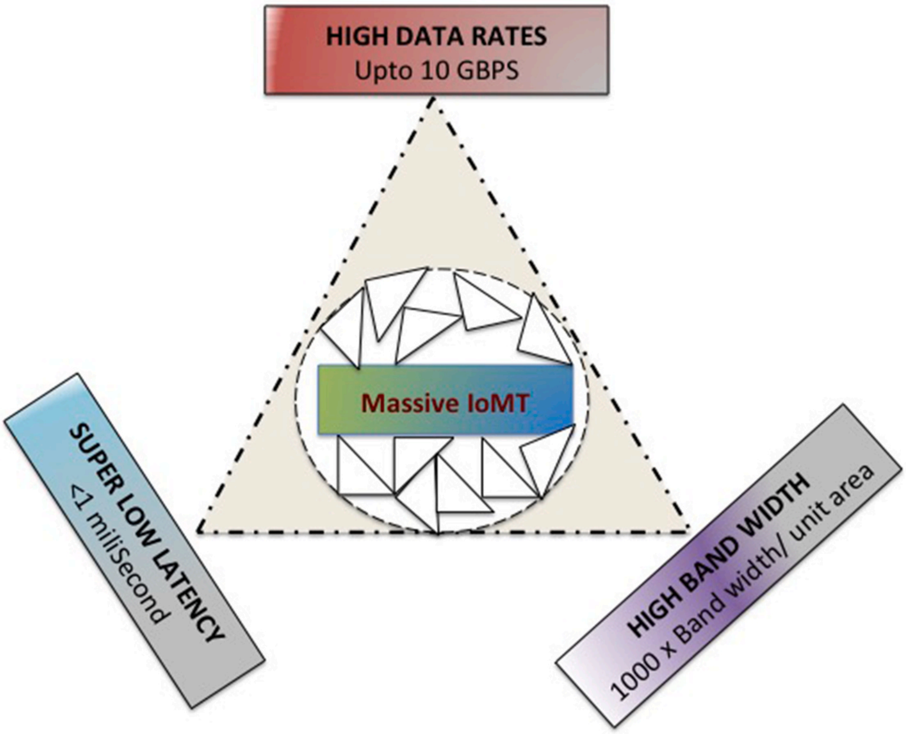

Fig. 4. Key features of 5G Technology. (i) High-speed data transfer rate [Up to 10 Gbps data transfer rate, that is a 10 to 100-fold improvement over 4G and 4G Long-Term Evolution (LTE)] (ii) Super-low latency or delay in the data transmission-response system; (iii) Connectivity and capacity; and (iv) High bandwidth and durability per unit area.

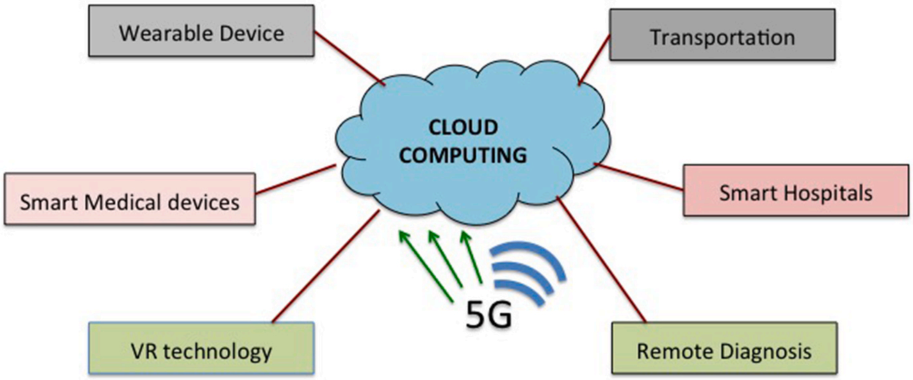

Fig. 5. Schematic representation of applications of 5G in healthcare.

using 3 integrating factors-biometrics, password, and smart card, ensuring preserved time bound user anonymity for multi-server e-health systems that was capable of simplifying the network load facilitating saving of database cost significantly.[44]

5.4. *Big data visualization and analytics (BDVA)*

The enormous data accumulated from IoMT devices needs to be analyzed appropriately for accuracy in decision-making. An efficient solution to this emerged in the form of Big Data Visualization and Analytics (BDVA) characterized by features like volume, variety, velocity, veracity, validity, volatility etc.[45,46] (Fig. 6).

Cloud computing emerged as a fundamental support to deal with Big Data by using internet based storage and data accessibility from any location. Later fog computing and edge computing resolved the problem of continuously increasing data obtained from all connected devices on routine basis.[47,48]In the healthcare realm, Big Data Analytics aid in predicting disease outcomes, treat epidemics, avoid avertible deaths and improve quality of life. The system collects the data from wearable sensor along with climate, temperature, environment, location and medical data in the form of either structured, unstructured, and semi-structured data integrated and visualized in cloud computing. The database analytics processes the data by extracting, cleaning and statistical analysis before forwarding to doctors or remote users.[49,50]

5.5. *Artificial intelligence (AI)*

In healthcare, AI techniques use clinical, laboratory and demographic data to screen, diagnose and predict prognosis of various diseases. During Covid 19 also, considering the need for rapid identification/early screening, several studies have been conducted using AI methods.[51] AI can facilitate detection, large-scale screening, monitoring,

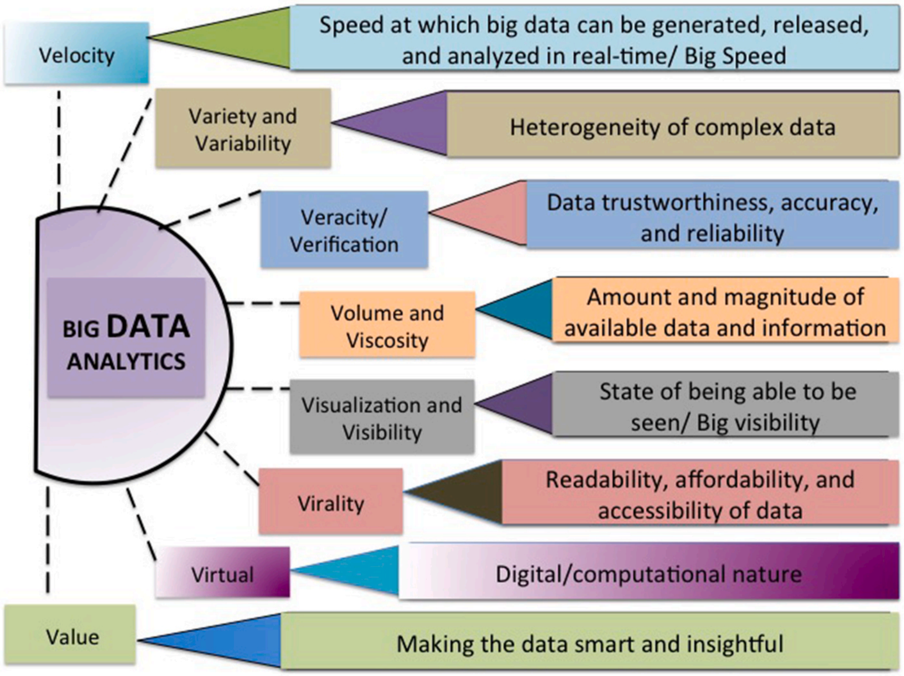

Fig. 6. Characteristics of big data visualization and analytics.

resource allocation, and prediction of possible interactions with the new proposed therapies.[52,53]

The literature concerning AI in healthcare is increasingly rich. Jiang et al., 2017 listed leading disease types where AI use was reported in the literature in decreasing order of frequency as cancers, nervous system, cardiovascular, urogenital, pregnancy, digestive, respiratory, skin, endocrine and nutritional.[54] Pantanowitz et al., 2020 developed AI-based algorithm enabling detection, grading and evaluation of digitized slides of prostate core needle biopsies in a pathology laboratory.[55] Somashekhar *et al* demonstrated a reliable AI system- IBM Watson for assisting the diagnosis of cancer through a double-blinded validation study.[56] Esteva et al., 2017 used AI to analyze and identify subtypes of skin cancer using clinical images.[57] Bouton *et al* developed an AI system for quadriplegic patients that facilitated restoration of movement control.[58] In another study, upper-limb prostheses was controlled using discharge timings of spinal motor neurons employing an offline man/-machine interface.[59] AI was also used to enhance the accuracy of diagnosis in congenital anomalies using phenotypic features from case reports.[60] Even diagnosis of heart disease using cardiac image has been done using AI system.[61] FDA has approved 'Arterys' Cardio DL application, which uses AI based on conventional cardiac MRI images to provide automated, editable ventricle segmentations.[62,63] Similarly abnormal genetic expression of long non-coding RNAs was used to diagnose gastric cancer with the help of AI.[64] Also an electrodiagnosis support system for localising neural injury using AI was developed by Shin *et al.*[65]

5.6. Block-chain

As understood, in smart healthcare systems, a large amount of data sharing is indispensable among medical devices and healthcare providers. This often leads to data fragmentation that may create a void in transmitted information, leading to insufficient information deciphered thereby hampering the therapeutic process.

To overcome this, 'Block-chain' technology was evolved to establish a connection among the data repositories present in the network. The Block Chain is 'a growing list of records (blocks) where records are connected to each other using a cryptographic method called hashing. Each record contains a cryptographic hash of the previous record, to chain the records together and make them resistant to modifications'.[66]

A secured block-chain transmission operates simultaneously from multiple devices and is characterized by an immutable "ledger" that is accessible to people and also controlled by them such that once a record is stored, it cannot be modified. The block-chain follows a smart contract mechanism wherein the identity is managed and accordingly permissions are set for accessibility to the data stored in the block-chain. Therefore, health care providers are only allowed to access those EMRs for which they have been permitted.[10,67] A blockchain based information management system 'MedBlock' has a highly secured access control and cryptography that enables efficient EMR access and retrieval.[68,69]

Yue et al. developed 'Healthcare Data Gateway (HDG)' based on block-chain technology that authorizes the patients to share their information without violating the privacy policy.[70] Vangipuram et al., 2021, developed 'CoviChain' to support secured transfer of COVID-19 infected persons' data to the hospital system using a block-chain implementation and edge infrastructure.[71] To combat COVID-19, Alsamhi et al. developed Block-chain configuration for multi-robot and decentralized multi-Drone.[72,73]

6. Applications of IoMT in healthcare

The changing face of old healthcare system into a smart and personalized system is attributed to the advent of newer devices pivoted around IoMT based technologies. Covid 19 has added to the usage of many existing IoMT based devices. On the contrary, innumerable number of devices have been constructed specifically for COVID19. Some of the applications of IoMT are described below (Fig. 7).

6.1. Testing and tracing for disease spread

Testing and tracing has been the key concern for disease spread control worldwide particularly in order to retard the spread. Several IoMT based devices have been employed for testing and tracing people

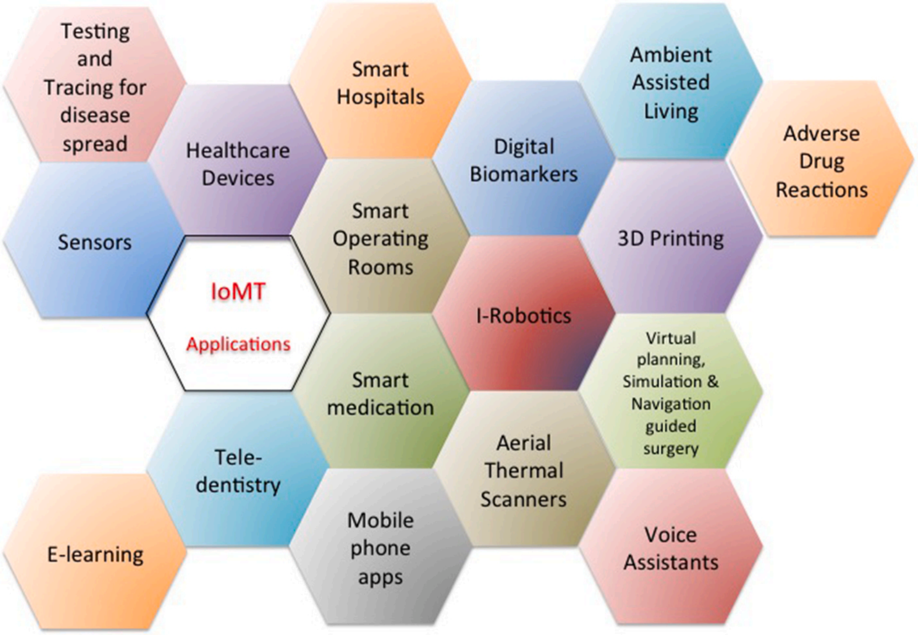

Fig. 7. Schematic representation of applications of IoMT in healthcare.

who are infected and to identify the patient's location so as to trace the possibility of disease spread. The IoMT based point-of-care testing (POCT) devices help with health experts to deal infectious diseases like malaria, dengue fever, influenza A (H1N1), human papilloma virus (HPV), Ebola virus disease (EVD), Zika virus (ZIKV), and coronavirus (COVID-19) more efficiently. Bibi et al., 2020, developed an IoMT based framework comprising Dense Convolutional Neural Network (DenseNet-121) and Residual Convolutional Neural Network (ResNet-34), for quick and safe real-time testing, diagnosis, and treatment of leukemia with the help of cloud computing.[74] The year 2020 brought with itself challenge in predicting individual's COVID-19 infection status and therefore marked use of several IoMT devices using various technologies. A machine learning model was developed that used patient's demographic features (age, sex, race) and 27 routine laboratory tests to predict initial COVID-19 RT-PCR positivity in 66% individuals whose RT-PCR result changed from negative to positive within two days.[75] Similarly, machine learning and deep learning methods including Convolutional Neural Networks (CNN) was used to detect early COVID-19 infection with 94.03% accuracy using chest X ray, CT and ultrasound image data.[76] Ahmed et al. (2021) compared a collection of four transfer-learning models- ResNet152V2, DenseNet201, VGG16, and Inception ResNetV2 with individual models for early diagnosis of COVID-19 infection. It was observed that the collection of pre-trained models provided more efficient results than individual models.[77]

6.2. Sensors-

Medical devices with in-built sensors can screen infections and monitor real-time health status of symptomatic patients. The IoMT framework of the device can determine the patient's heartbeat, cough, temperature and Oxygen concentration (SpO_2) using customized algorithm.[78] Sensors used to identify and notify physical and biological activities can be cardiac activity/ECG sensors, respiratory sensors, dental sensors and foot drop sensors.

Kakria et al. used smartphone and wearable Sensors to determine Real-Time Health Monitoring for Remote Cardiac Patients.[79] Washington University School of Medicine in collaboration with School of Engineering and Applied Science developed biological sensors embedded with the gingival lining, for measuring the specific peptides active in periodontal diseases. On detecting bone loss specific peptides, the device sends a notification to alert both the patient as well as the practitioner for earliest prompt action. Similarly, gingival sensors can analyze saliva and gingival crevicular fluid sample to detect early periodontal diseases. IoMT based pressure sensors can also be used to plan effective treatment and restoration in patients with bruxism. The mouth-guards have pressure sensors that can identify the areas of teeth that are affected most due to clenching and grinding. Sijobert et al. (2021) developed a Sensor-Based Multichannel functional electrical stimulation (FES) System to control knee joint and phase asymmetry in gait using foot drop/gait sensors.[80] Similarly Sakamoto et al. (2021) developed stretch strain sensor (STR) to analyze foot motion.[81]

For posture correction, another system comprising combination of smart necklace, notebook computer, and smartphone have been developed. The notebook computer is enabled with a depth camera capable of identifying skeletal structure joint reference points and after reading the relevant data and computation related to those reference points, it alerts smart necklace to enable calibration of the smart necklace housing a microprocessor unit-6050 sensor to standard values for posture assessment. When smart necklace detects poor posture it sends a reminder at the user's smartphone having a mobile app to correct his or her posture.[82]

Necklace sensors with embedded piezoelectric sensor that can also be used for food-intake monitoring system. It has a small Arduino-compatible microcontroller, Bluetooth LE transceiver, and Lithium-Polymer battery that coordinate according to motion in the throat with a mobile application for processing the information and guiding the user.[83] Similar multi-sensor, low-power necklace was developed by Zhang et al. (2020) and designated as '*NeckSense*'. This captured information about an individual's eating quality, quantity and frequency in a day to facilitate food counselors in providing appropriate real-time interventions.[84]

During COVID-19 epidemic that abundantly focused on frequent and accurate washing of hands since the practice could prevent the spread of microorganisms, sensors attached to hand washing dispensers or stand-alone devices facilitated monitoring of accuracy and frequency of hand-washing.[85]

6.3. Healthcare devices-

Adoption of IoMT enabled healthcare devices became a more common custom primarily during COVID-19 that emphasized more on use of remote health monitoring devices like smart inhalers, Oxygen saturation monitors, blood glucose monitors including smart pens, smart wearable devices like smart watches, smart implants, smart tooth brushes, sleep trackers, loneliness detectors.

Merchant et al. (2018) demonstrated use of Bluetooth-enabled smart inhalers and predictive analytics to help patients and their health care team dealing with respiratory conditions like asthma. Research has shown these IoMT devices aided in reduction in usage of inhalers through improved symptom identification and self-management.[86]

A non-invasive tissue oximeter was developed by Fu et al. (2015) to measure blood oxygen saturation level, heart rate and pulse parameters using Zigbee or Wi-Fi to adjudge medical intervention.[87] In another study, an alarm system integrated with a pulse oximeter and WLAN router, was developed that alarms the patients on detecting a drop in oxygen saturation below the critical level.[88]

Several projects have been developed in different clinical contexts to explore the use and adoption of Smart Wearable Health (SWH) devices like Smart watches, accelerometers (fall detectors, iFall), glucose monitors and smart insulin pens, loneliness detectors, sleep trackers; wireless electrocardiogram monitors and wearable blood pressure monitors in routine medical practice. Research by Global Data estimates an increase in the global healthcare SWH devices market from nearly $27 billion in 2019 to a whopping $64 billion by 2024.[89]

The Health professionals including dentists have the choice of multiple software for practice management linked to mobile apps connected with smart watches that enhance the productivity and efficiency to provide a better workflow and time-management practices thereby allowing greater number of patients to be catered. AI-powered mobile apps are developed that have voice input of patient data and allows health practitioners'/dentists' voice commands to fetch the relevant patient data and images like clinical photographs and x-rays to be displayed on the monitors.

Another important sector facilitated by IoMT and AI is the insurance sector that can develop a precise picture of the actual treatment need based on IoMT and AI supported devices resulting in personalized health insurance plans. This also lowers the premiums required by predicting likelihood of future claims.

Demand of smart wearable devices such as smart watches, smart bands and finger rings has been triggered due to COVID-19 since the wearable devices supported tracking and contact tracing, broadcasting knowledge about health, ensuring social-distancing, and providing mental healthcare by tracking an individual's cognition and mood in real-time, thereby enabling personalized interventions.[90–94] During COVID-19, WHOOP system was developed that could identify COVID-19 positivity in 20% of individuals two days prior to onset of symptoms and in 80% by the third day of symptoms.[95] Disposable patches and biosensors were also developed for early detection of COVID-19 patients deterioration by measuring various vital predictors like respiratory rate, heart rate, activity level, posture and ambulation.[96,97]

Blood glucose monitoring is another application of IoMT employing a bio-sensing technology and advanced signal processing characterized by use of several interconnected small wearable devices.[98] Bhatia et al. (2020) demonstrated an effective IoMT based home-centric Urine-based Diabetes (UbD) monitoring system using Recurrent Neural Network (RNN).[99]

Diabetes Assistant (DiAs) employs Android based smartphones to act as functional input device and their displays being used as Body Gateway and Network Hubs for the telemedicine services. Both these components coalesce and communicate through Bluetooth.[100] 'Accu-link' is a proprietary modem allows transfer of data from glucometers to an application installed on a server at their consulting doctor's clinic. Another similar application, 'DiaSend' can integrate data from all major glucometers on the market along with many brands of insulin pump.[101]

The 'Mobile/Share and Follow App' monitors the real-time glucose data and trends to notify critical situations desiring immediate actions.[102] Remote monitoring of blood glucose values in preterm newborns admitted at the Neonatal Intensive Care Unit required 'Neokid' that not only supports monitoring of blood glucose but also provides computation of the infusion rates and dispense hypoglycemic drugs/insulin automatically.[103] For glycemic control in Type 1 Diabetes mellitus, several types of smart insulin pens like InPen, ESYSTA, Pendiq, YpsoMate SmartPilot, NovoPen 5 Plus, NovoPen Echo, Vigipen, and KiCoPen exist.[104] However, the most crucial development is AP (Artificial Pancreas), a minimally-invasive automatic device based on the measurements collected by a real-time CGM sensor for modulation of insulin infusion.[105]

Another major outcome associated with adverse health conditions observed in COVID-19 pandemic is the loneliness and lack of social well-being. Wetzel et al. investigated the informative value of smartphone communication app (CORONA HEALTH APP) data for predicting subjective loneliness and social well-being in Germany and reported relatively high levels of loneliness and low social well-being.[106] Detection of loneliness through passive sensing on personal devices highlight intervention opportunities through mobile technology (smartphones and Fitbits Flex 2) to reduce the impact of loneliness on individuals' health and well-being.[107]

Ong et al., 2020 investigated lockdown strictness related objective sleep and resting-heart rate in consumer sleep tracker users and reported delayed mid-sleep times variability and resting heart rate.[108] Apart from this Smart watches and Fit bits were also used to track activity, heart rate, and sleep patterns. Fall detectors like iFall (Android-based smart phone integrated wearable tri-axial accelerometer) is an alert system for fall detection using data from the accelerometer. When a fall is suspected, an alert is seeking user's response is sent, when the user does not respond, the system alerts the pre-specified social contacts with an informational message via SMS. When contact responds, the system provides an audible notification and automatically connects and enables the speakerphone. If a social contact confirms a fall, an appropriate emergency service is alerted.[109] Khan et al. developed a fall detector for patient falls in hospitals, using a camera, gyroscope and accelerometer, interfaced with small single board microcomputer. The information received from the camera and the sensor data is analyzed and upon detection of a fall, an attendant at the hospital is informed.[110]

Similarly, 'Smart' implants like cochlear implants, cardiac implants, joint implants and Smart dental implants have also been developed. In these various microchips/wireless sensors are placed on the surface, or embedded inside the area of concern. Depending upon functions to be monitored, these collect patient data for instance, smart dental implants collect data related to bruxism, food intake, activity levels, and brushing habits along with monitoring of pH of saliva, salt, glucose, and alcohol intake. The collected data can be transmitted over to the server to be transferred to a mobile app/device, prompting immediate necessary treatment regime. By monitoring the salivary pH data, patients at elevated risks of cavities can be identified suitable preventive measures can be recommended. However, the main challenge lies in developing small-sized smart implants to minimize discomfort during and after implantation and having high-volume cost with a time-efficient, compact, impedance matched (50 Ω, required by most modern electronics) and efficient antenna.[89]

Smart Toothbrushes embedded with camera and pressure sensors gather patient data and track the appropriateness of brushing activity to be shared with the dentist in real-time and thus fastening the preventive care process. Advanced connected brushes are quite useful in preventive dentistry since the progression of dental diseases in the preliminary stages can be intervened. These brushes take intraoral images aid in comprehensive intraoral examination. The data is sent to the server where Artificial Intelligence algorithms analyze them for cracks, caries or any other abnormalities requiring attention and via mobile apps notify to make an appointment at the dental clinic. Additionally, Smart brushes can detect acidic saliva which can warn the patient and dentist against developing caries or gum disease thereby improving timely patient oral care.[111] Some smart brushes can sense specific chemicals in the patient's breath that aids in pre-diagnosis of diabetes. Lee et al. (2006) developed 'intelligent toothbrush' that uses accelerometer and magnetic sensors to monitor motion and orientation during brushing through the grip axis. These use miniature low-power micro-controller MSP430 to measure the direction toothbrush with respect to the earth's magnetic field and its activity. The data is transmitted via 2.4 GHz radio transmitter nRF2401 to computer for analysis and extraction of relevant information.[112,113] *Prophix,* is another smart toothbrush with inbuilt HD camera having capability to connect via blue tooth and wi-fi to the mobile apps. Similarly Beam Dental smart toothbrushes, powered by microchips are capable of analysing frequency, efficiency and pattern of brushing. Jeon et al., 2021 demonstrated effectiveness of AR based training using smart toothbrush on oral hygiene care in people with intellectual disabilities.[114] Smart toothbrushes have also been used as an appropriate counter measure to maintain oral health and hygiene in pandemic situation.

6.4. *Smart hospitals*

A smart hospital focuses on optimized automated processes employing IoMT-based interconnected environment to create an effective connection between patients, health care providers and machine for improving patient care. While developing a Smart Hospital, four key areas are needed to be considered - patient services and interfaces; care processes and orchestration; logistics and support services; and organization and capability design.[104,105] Considering the existing pandemic, smart hospital can provide many services for patients at remote areas or their homes and reduce hospital visits. Facilities like tele-medicine, real-time monitoring of patients, use of robots and online processing of the big data produced aid in improving healthcare quality. Robots can be used to perform tasks such as deliveries and transports of medicines and reports, provide information to help people navigate within hospitals, detect abnormal actions, and collect patient data etc thereby diminishing close contacts.

Use of artificial intelligence can also facilitate better resource management and improve the quality of care at reduced costs. In addition, other technologies such as 3D printing to produce needed instruments for operations, virtual reality for rehabilitation and entertainment in order to strengthen the spirit alongside with augmented reality which is very useful during operations, RFID to better control of the resources, devices and patients can be provided in smart hospitals to manage and control such diseases better.[115]

6.5. *Smart Operating rooms*

Okamoto et al. (2018) developed IoMT enabled operating room known as "Smart Cyber Operating Theatre (SCOT)" that possessed Open Resource interface for Network (ORiN) technology for connecting medical devices.[116] Another SCOT that has been developed includes next-generation networking facility known as OPeLiNK communication interface exhibiting intraoperative magnetic resonance imaging (MRI).[117] Smart Operating rooms with Robotic system that can reproduce the hand motions of a surgeon by increased degrees of freedom via haptic supported enhanced sensation ability, tissue recognition and real-time diagnosis. The precision of surgery is also enhanced owing to reduction in hand tremor and enhanced visualization provided by high-definition 3-dimensional video images.

Another concept popularly known as remote tele-surgery is gaining popularity where surgical procedures are performed even when surgeon and the patient are at extreme distances, by using robotic arm mediated replication of the surgeon's actual hand motions to the surgical instruments over the patient's tissue.

Hybrid Operating rooms allow surgeons to perform combined open, minimally invasive, image-guided and/or catheter-based procedures in the same operative setting. Ushimaru et al. utilized RFID for surgery to improve visualization of the surgical procedure and improve the safety by optimal usage of surgical devices.[118]

AR system can also be used to visualize volumetric information projected upon the patient's organ during surgery. Similarly, internal pathology of solid organs can also be visualized without incision using overlaid virtual images. To remove tumors more efficiently, the surgical team can use high-definition, 3-dimensional, real-time image guidance.[119–121]

6.6. *Smart medication*

Digital (smart) medications have IoMT sensors embedded in individual tablets can be used to monitor biomarkers, antibiotics' levels in body fluids, antibiotic compliance, dosage monitoring in order to provide more accurate information of the efficacy of treatment on a personalized level.[122]

An ingestible sensor (micro-fabricated sensor made from copper, magnesium, and silicon, in minute quantities), communicates with an external body sensor such as a wearable sensor patch through a mobile app or web portal. Information gets stored on the cloud and is used to measure medication adherence, absorption, activity and heart rate. The mobile app can also be used to prompt the user to take their prescribed medication as scheduled and share information with family members or care providers. Plowman et al., 2018 demonstrated use of smart medication for treating uncontrolled hypertension and diagnosing asymptomatic diseases.[123] Naik et al. also demonstrated use of CE-marked ingestible sensor to assess patients with persistent hypertension.[124]

6.7. *Digital biomarkers*

Self-powered IoMT-connected diagnostic devices are developed that provide potential real-time monitoring of biomarkers in and on the human (or animal) body fluids e.g., sweat, urine, blood etc. This can facilitate distinction between viral and bacterial infections and personalized predictive algorithms can be utilized for identifying infection, sterile inflammation or the possibility of relapse, up to hours before visible physical signs are observed. Also, the reaction of the patient to treatment could be monitored more closely, indicating if the patient is actually responding to therapy and possibly indicating that resistance may be present, allowing clinicians to consider adapting their 'first line' treatment therapy in a timely manner.[125–137]

Wessels et al. (2021) on the basis of primary tumor tissue analysis using Convoluted Neural Netwoks (trained by Haematoxylin and eosin stained primary tumor slides from 218 patients) developed a novel digital biomarker based to predict lymph node metastasis.[138]

An IoMT based biosensor 'RapidPlex' was grafted for assessment and quantification of COVID-19 biomarkers like nucleo-capsid protein, inflammatory C-reactive protein (CRP), IgM and IgG antibodies in the sample. The Laser-engraved graphene (LEG) electrode is functionalized with antigen specific antibodies that can detect target molecules and their hybridization reaction is depicted as current intensity.[128,129]

6.8. *I-robotics*

IoMT-aided robotic system is a smart environment comprising multiple interconnected advanced integrated systems comprising humans, robots and IoMT-system. The system mostly uses cloud-robotic system that can access a large amount of data and process the information using sensing, computing and memory to perform specific tasks.

The development of robotic technology aims to achieve human-like automation so as to reduce human intervention. The system employs Machine-learning algorithms to program and train robots/machines to act either on the basis of patient's health information data received through the network among health professionals or by using the intelligent computation to perform in the medical environment.[130,131]

Miseikis et al. developed ‘Lio’, a healthcare robot that uses a combination of visual, audio, ultrasound, laser, and mechanical sensors to avoid collision autonomously. This enables safe navigation for staff and patients in a hospital.[132] Similarly, “Guido”, a smart-walker has been developed for visually impaired person that uses a map-based navigation system to create a map of the surrounding to track the position and use of a collision avoidance algorithm to create a path to reach the destination without any obstacle.[133]

Another robot known as “Nao Robot” is capable of interacting with the patients after analysing the medical data and guides them about vital signs status of their body, predict the risk of heart diseases in the future and recommend the necessary changes in the lifestyle to avoid associated complications.[134]

Another IoMT-aided robotic system enables recording of specific motions by the therapists to be recreated in patients with defective limb movements.[135] ‘ROBIN’, a rehabilitative robot provides stability to the trunk during postural changes and facilitate simple arm and hand movements for reaching and grasping things.[136]

Apart from those mentioned, several service robots for elderly like Care-o-Bot, Aibo, CAESAR, JoHOBBIT, and PT2, with help of IoMT technologies (sensors, RFID, GPS, infrared, and wearable sensors) connects the elderly with health professionals and family members thereby supporting in maintaining a quality of life by providing reminders, fall detection, and interfacing with other home appliances.[137]

In hospitals also, autonomous robots have been employed for biomedical waste management and disinfection. In addition these can deliver medicine, food, or medical supplies to patients. A wheeled telepresence robot has been developed that can perform virtual face-to-face patient assessment and also perform diagnostic tests after collecting the swab samples from the patients.[138]

In public areas, during covid19, maintenance of social distancing and wearing of masks could be checked by Mobile robots and supervision of quarantine areas could be done using Aerial robotics.[139] Even complete diagnostic test to check the COVID-19 infection could also be done by a cost-effective medical diagnosis humanoid (MDH) developed by Karmore et al.[140]

6.9. Aerial thermal scanners-

Tele-thermographic systems or thermal imaging systems (TIS) have inbuilt thermal infrared camera having a temperature reference used to detect skin temperature accurately without any physical contact with the person. These quick and non-invasive systems are quite useful to identify raised body temperatures in dense populated areas. On detecting raised body temperature, they may alarm the healthcare teams to test the person for presence of illness. Mohammed et al., 2020 implemented an IoMT-based drone technology with inbuilt thermal camera to identify raised temperature associated with coronavirus infection using the thermal images.[141]

6.10. 3 dimensional scanning and printing

IoMT based 3D scanners makes a digital recording of intraoral impressions to allow replication of hard and soft tissue structures within the mouth with accuracy in relatively short time thereby avoiding inconvenience associated with traditional impression materials.

The benefits of this technology include reduction in overall process time reducing the amount of labor, increase in efficiency, improved workflow, reduction in errors and cost efficacy attributed to capability for sharing of the virtual digital impression with lab technicians and construction of immediate restorations and prosthetic rehabilitation using 3D printing technology for eg. Stratasys, Envisiontech or FormLabs and other pioneers in 3D printing use CAD- CAM to print the crown as per the image data provided to the machine.[142,143]

6.11. Virtual planning, simulation & navigation guided surgery

Image-guided surgery comprises of personalized simulation, preprocedural planning, and practice drill of the planned surgical intervention within the specific anatomic environment of the individual patient to provide more specific and targeted surgical treatment. A well-simulated environment permits real workflow of operating rooms wherein procedures are mimicked, tested, and custom-modified as per patient and also acclimatize the surgical team for the actual task. This simulation also teaches and trains the assisting staff by testing the concepts and systems before their introduction enabling adaptation to the technological details thereby improving performance and outcomes.

A preoperative mapping of tumor margins using computed tomography and/or magnetic resonance imaging followed by virtual planning of the surgical resection assists in intraoperative navigation during actual resection of advanced tumors.[144]

6.12. Mobile and smartphone applications (apps)

Association of mobile computing, sensors, communication technologies using personal area networks and mobile networks and cloud computing can be used to provide an efficient healthcare services that can track health information of the patient.

An IoMT based mobile gateway system “AMBRO” was designed to detect fall and control heart rate using multiple sensors that used an integrated GPS module to locate the patient.[145]

A smart phone app based COVID-19 monitoring module is developed that enables the remote recoerding of medical data by patients and their families themselves thereby alleviating the need to visit hospitals for the same.[43] Similarly, Contact tracing for infectious diseases has been automated using mobile applications. Corona contact tracing apps are a novel and promising measure to reduce the spread of COVID-19 for example ‘Corona-Warn-App’ in Germany; ‘SwissCovid’ in Switzerland and ‘Arogya Setu’ in India.

6.13. E-learning

The use of various electronic devices (e.g. computers, laptops, smartphones, etc.) and software/apps such as Google Classroom, Zoom, and Microsoft Teams etc have changed the face of learning experiences internet supported online teaching and learning. This latest face of learning termed as E-learning was not a very popular practice in the past particularly in developing countries due to challenges like incomprehension towards E-learning medium, deficient adequate internet connectivity and requirement of adequate technological knowledge and skills that hampered the universal adaptation of E-learning. For strengthening E-learning formal training and workshops on using various technological methods and platforms needs to be encouraged.[146,147]

The COVID-19 pandemic crisis forced the entire world to adopt e-learning for not only educating students in academics but also instructing patients about remote care. Furthermore, the current unpredictability of returning to previous ‘normal’ life and vanishing of this pandemic highlights the need for maximum dependency on e-learning even for higher education. Therefore the current new curriculum has been transformed from the traditional teacher-centric to student-centric model. Adamus et al. reported a higher rate of women’s preference for accepting e-learning than men’s probably due to difficulties to balance with work-personal life balance that became relatively manage with online mode.[148]

6.14. Tele-dentistry

The use of telecommunications in dentistry via networking and sharing digital information (using phone, photos or videos), remote distances analysis of clinical information and images for workup and distant consultations facilitating delivery of oral health care and oral health education services is the new emerging concept termed 'Tele-dentistry'.[149,150] It requires possession of smartphone by the patient having adequate Internet access and a cloud-based tele-dentistry platform by the dentist that can support streaming of videos in real-time with facility to store and forward the photos and collected clinical data from the electronic health record (EHR). This platform can aggregate all the data for remote evaluation and recommendation for the treatment by the dentist.

The American Dental Association also issued a policy on tele-dentistry that offers guidance on the modalities to be followed. This will enhance the general practice of tele-dentistry.

The sudden encroached pandemic state around the world has necessitated the use of tele-dentistry like never before. Tele-diagnosis, an inevitable part of teledentistry has gained usage during COVID 19 particularly due to inability to visit doctors or dentists. This advocates the use of smartphones for detection of dental caries, screening of oral potentially malignant or malignant lesions.[151,152] Haron et al. developed 'Mobile Mouth Screening Anywhere' (MeMoSA) to facilitate early detection of oral cancer particularly beneficial for patients with limited access to specialists.[153] Similarly Skandarajah et al. developed a tablet-based mobile microscope (CellScope) device as an adjunct for screening of oral cancer.[154]

Despite the continued advancements, more research is needed to determine the technology needs and types of oral healthcare problems that can be safely addressed using tele-dentistry.

6.15. Voice assistants

For delivery of remote health care in recent times tools like Voice Assistants in the form of Google Assistant, Apple Siri and Amazon Alexa have been quite helpful. Sezgin et al., 2020 developed voice assistants as an alternative modality for supportive health care during health crisis/pandemic.[155] The Chatbot created by Centers for Disease Control and Preventions (CDC) and Microsoft uses evidence-based information for creating a COVID-19 text-based platform. The World Health Organization (WHO) also released a WhatsApp text-based chatbot to respond to public queries about COVID-19. Apple's VA is an app that shares COVID-19 information and updates using CDC resources accessible through Siri. Alexa VA from Amazon helps users to setup routines during home stay and provide information and guidance about COVID-19.[156–159]

6.16. Ambient assisted living

Ambient assisted living (AAL) is AI supported living where aging people are assisted to live independently, with convenience and safety within their home. The main purpose of AAL is real-time monitoring so that when medical emergency occurs, provisions for human service-like assistance can be made.

It utilizes advanced integration of multiple systems like AI, big data analysis, machine learning for activity and environment recognition along with monitoring of the vitals like blood pressure, heart rate, respiratory rate etc. .

An automated modular architecture for security and communication has been developed using IPv6-based low-power wireless personal area networks (6LoWPAN). For communication, closed-loop communication service using RFID and NFC have been employed for establishing a connection between patient and healthcare providers.[160] Monitoring of chronic conditions and medical emergencies in elderly people can also be done by emergency detector developed to assist and alert the caregivers.

IoMT-based healthcare systems using assistive robots can also be employed to track quality of indoor air and trigger alerts to the caregivers when there is a reduction in the air quality below a standard value.[161,162] Similarly to detect fluid intake different wearable, smart containers, surface and embedded sensors can be used particularly in elderly patients.[163]

6.17. Adverse drug reaction detection

An IoMT-based Adverse Drug Reaction (ADR) system is based on a unique identifier/barcode present on each medicine to be taken by the patient. The information about compatibility of the medicine with the patient's body can be verified using a 'Pharmaceutical Intelligent Information (PII)' system since it stores the allergy profile of the patient using e-health records. Thorough analysis of allergy profile and other vital health information guides for suitability of the medication to the patient.

Since ADR may occur either after a single dose, after a long-term therapy or interaction of two different medicines taken simultaneously and the intensity of ADR depends upon time of drug intake and varies from person to person, it therefore becomes crucial to verify the possibility of ADR using IoMT based PII system.

Another IoMT-based ADR system known as Prescription Adverse Drug Event (prescADE) has also been proposed, which can improve patient safety by reducing the ADR.[164,165]

7. CHALLENGES of IoMT

Several challenges and implications exist today that need to be addressed before mass adoption of IOMT for instance privacy and security of data, data management, scalability and upgradation, regulations, interoperability and cost efficacy (Fig. 8).

7.1. Privacy and security of data-

One of the main issues and challenges in IoMT application is to ensure proper cyber safety within healthcare monitoring systems. Security of the huge volume of sensitive health data of patients transferred across systems pose a challenge yet to be dealt with.

Akhbarifar et al. (2020) developed a lightweight block encryption method for remote health monitoring having provisions for security of health and medical data in cloud-based IoMT environment.[166]

Lin et al., 2021 proposed a smartcard-based user-controlled single sign-on (SC–UCSSO) system for tele-medicine that preserves the privacy and enhances security and performance.[167,168]

'CoviChain' uses block-chain technology to address the security and privacy issues and avoid exposing individuals' data even while achieving larger data storage provision.[72]

7.2. Data management

Data management is the ability to access, integrate, control and manage data information flow. Data filtering techniques such as data anonymization/Data privacy, data integration and data synchronization, are used to provide only useable information for application and hide other details.

7.3. Scalability, upgradation, regulations and standardization

The ability of a healthcare device to adapt to the changes in the environment is termed as scalability. Therefore a highly scalable system is the one that maintains uniformity among the connected devices and can work efficiently using available resources smoothly without any delay. A highly scalable system remains more useable in both current and future times. Continuous development and advancements in IoMT technology has raised the need for regular updating of the existing device. This remains a challenge in the fast pace world.

In the healthcare industry, validation of the varying range of IoMT based devices based on the communication protocols, data aggregation, and gateway interfaces, manufactured at a large scale by multiple

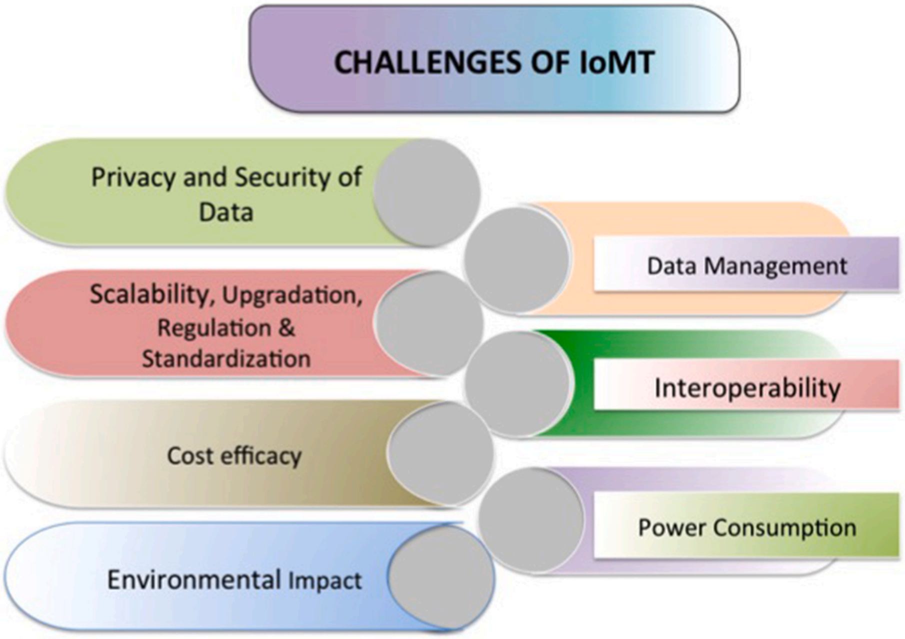

Fig. 8. Schematics illustration of challenges faced in mass adopting IoMT.

manufacturers or vendors claiming to have followed standard rules and protocols during designing process becomes essential. For such validation and standardization the competent authorities or bodies like Information Technology and Innovation Foundation (IETF), the European Telecommunications Standards Institute (ETSI), the Internet Protocol for Smart Objects (IPSO) becomes mandatory.

Also EMR recording IoMT devices needs to be validated. This can be achieved by collaboration of researchers, various organizations and standardization bodies. However regulatory challenges such as Health Information Technology for Economic and Clinical Health Act (HITECH), Health Insurance Portability and Accountability Act (HIPAA) compliance and general data protection regulation (GDPR) hinder rapid and large-scale adoption of IoMT devices.

7.4. Interoperability

There is variation in the standards supporting applications manufactured by different industries. Also heterogenity of devices and data obtained from numerous sources impede the magnitude of use owing chiefly to inter-operator variance. Interoperability poses challenge since data exchange among different IoMT systems with contrasting features becomes tricky. Therefore development of a standard interfaces becomes crucial particulary in applications that supports inter- organizational cross-systems. In the IoMT world, exchange of multiple variety of information creates an extensive volume of data and the processes involved in the handling of the data along with management of the interconnect devices in an interoperable way considering energy constraints, remains an essential challenge.[169]

7.5. Cost efficacy

Particular to Covid 19 times, financial stress has expanded to involve large number of individuals, companies and even organizations thereby limiting mass IoMT adoption. Therefore cost efficacy becomes a key challenge and requires adequate attention. The cost of development, installation, and usage of IoMT system needs to be acceptable.

The IoMT-based system have large number of connected medical devices and sensors. These have high maintenance and upgradation costs affecting both manufacturer as well as end-users. Hence, the inclusion of lower maintenance sensors with low initial setup costs will aid in development of more IoMT devices and increase their implementation on more routine basis.

7.6. Power consumption

Power consumption is another factor impeding the adoption of IoMT devices more routinely. Most IoMT devices are battery operated and once a sensor is put on, it either requires frequent battery replacement or use of a high-power battery. Current focus should be on designing a sustainable healthcare devices capable of generating power for themselves or assimilation of the IoMT system with renewable energy systems that can also contribute in mitigating the global energy crisis.

7.7. Environmental impact

As understood, the IoMT systems have various inbuilt biomedical sensors to perform functions. These are made up by amalgamating several semiconductors comprising earth metals and other toxic chemicals, that may affect the environment adversely. Therefore regulatory bodies control and regulate the manufacturing of the sensors. More research needs to be directed towards designing and manufacturing of sensors using biodegradable materials.[7]

8. Conclusion

India is a rapidly developing country lagging mostly in the standards of well-being as compared to developed countries. To overcome this gap, the biomedical and bioengineering fraternity is focusing on development of newer technologies and their extensive usage. Technologies like cloud computing, fog and edge computing, artificial intelligence, virtual and augmented reality, big data analytics and blockchain have enabled prompt and secured adoption of IoMT.

The health care system has received a major boost due to developments like Remote health monitoring systems and smart devices, telemedicine/teledentistry platform, robotics and drones that significantly contribute to disease prevention by enabling screening, early diagnosis, management and facilitated living. The ease in use of these devices for healthcare monitoring has outshined the need for hospital visit. But still the associated challenges need to be addressed for cost efficient, flexible and consistent systems fit for healthcare needs to enable mass acceptance.

Declaration of competing interest

Authors have no conflicts of interest to declare.

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