IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Digital Transformation In Clinical Trials: Virtual Clinical Trials And Data Management

[1]MS. KALYANI PANDHARINATH NEELAM KALE, [2]MRS.SANGITA N BHANDARE

[1]STUDENT, [2] ASSISTANT PROF. (DEPT. OF PHARMACOLOGY)

Pravara Rural Education Society's College of Pharmacy (For Women), Chincholi,

Nashik, 422102, (Maharashtra), India

ABSTRACT:

Clinical trials are essential for evaluating the efficacy and safety of novel medications and therapies. Planning, managing, and carrying out studies has changed as a result of the digital transformation of clinical trials brought about by the increased use of technology. The way that virtual platforms and data management facilitate this transition is the main topic of this review. Data was collected from online scientific sources and published articles. Artificial intelligence, remote patient monitoring, and electronic data capture are examples of digital tools that enhance trial speed, accuracy, and patient involvement. Data security, a lack of digital infrastructure, and regulatory obstacles are still problems, though. All things considered, clinical trials are becoming more effective, patient-friendly, and flexible for upcoming studies thanks to the use of digital and virtual methods.

Index Terms: Clinical trials, Virtual clinical trials, Data management, Decentralized clinicals trials

I.INTRODUCTION

A clinical trial is an investigation intended to show the effectiveness and safety of a medication, treatment, medical instrument, or diagnostic evaluation. Because clinical trials involve human research, they need to be meticulously planned and must adhere strictly to a series of ethical standards. Logistical challenges, ethical limitations, expenses, and extended A clinical trial is an investigation intended to show the effectiveness and safety of a medication, treatment, medical instrument, or diagnostic evaluation. Because clinical trials involve human research, they need to be meticulously planned and must adhere strictly o a series of ethical standards. Logistical challenges, ethical limitations, expenses, and extended execution times may negatively affect the conduct of clinical trials.To address these challenges, the industry has gradually been transitioning towards greater implementation of virtual clinicaltrials. VCTs employ technological gadgets and social interaction platforms to carry out trials remotely from a patient's residence. These digital methods provide fresh possibilities for a patient- These digital methods provide fresh possibilities for a patient-focused perspective on clinical research(2).

Clinical trials' primary goal is to ascertain the efficacy and safety of any treatments, and the methods used to accomplish this have been developing for more than a century. In order to assess the growing number of advancements in medical care, the number of clinical trials is growing by 7-8% annually. The amount spent worldwide on new medication clinical trials was around US$48.4 billion in 2020; by 2030, this amount is predicted to increase by 6% annually to US$82.5 billion. However, despite this investment, a significant percentage of studies have low retention rates or fail to recruit to time and objective. For These digital methods

provide fresh possibilities for a patient- biopharmaceutical businesses, the cost of a clinical trial's failure includes not just the trial's execution costs but also all of the earlier work completed(3). Remote trials that use digital technology and home-based treatment might lessen the strain on patients, potentially improving retention rates; they can also increase recruitment by bridging geographic divides. These are referred to as "virtual," "home," "decentralized," "remote," or "siteless" trials. We have decided to adopt the term decentralized clinical trials (DCT) to ensure uniformity.

In contrast to a clinical trial site, they often entail assessing the impact of a clinical intervention (typically a pharmaceutical product) in the homes of research participants. Clinical trials that use digital health technology for all or part of the study and allow for remote participation outside of conventional brick-and-mortar study facilities are referred to as virtual trials.

The lengthy and intricate process of clinical drug development takes six to fifteen years. The largest factor contributing to clinical trial delays is patient recruiting, which accounts for 30% of phase 3 study terminations. Roughly 80% of studies fall short of the original enrollment goal and schedule. Pharmaceutical businesses may lose up to USD 8 million in revenue every day as a result of these delays. Additionally, the annual cost of patient recruitment is close to USD 6 billion. Furthermore, only a small percentage of the world's eligible population takes part in clinical trials, and those who do typically visit the trial site 11 times during the course of six months(3).

A relatively new and underutilized approach to doing clinical research using online social interaction platforms and technologies (such as apps and electronic monitoring devices) is virtual clinical trials. VCTs are a modification of clinical trials that make them more affordable, time-efficient, and participant-friendly rather than a brand-new or distinct kind of clinical study. VCT is able to boost participant diversity and representation, improve retention, and recruit more quickly by utilizing digital health technologies(1).

Additionally, VCT involves a small number of study sites under the direction of primary investigators, whose team reviews all data as it is given in real time to keep an eye on participant safety and health. A remote study coordination center facilitates all research efforts and manages studies centrally. This is not like traditional clinical studies, which have numerous study sites and staff that add to the cost. Additionally, VCT involves a small number of study sites under the direction of primary investigators, whose team reviews all data as it is given in real time to keep an eye on participant safety and health. A remote study coordination center facilitates all research efforts and manages studies centrally. A. This is not like traditional clinical studies, which have numerous study sites and staff that add to the cost(1).

II.EVOLUTION OF CLINICAL TRIALS

The high ethical, scientific, and legal standards reflected in current practice can be explained by the history of clinical research. A slow, historical development of scientific approaches like blinding, randomization, comparison of interventions, and placebos in clinical trials shows how these methods work together to continuously improve clinical care. Over time, advancements have been both clinical and ethical. Due to time limits, many investigators do not fully appreciate the Belmont Report, which was created in response to serious misbehavior and represents the highest ethical standards. Researchers may be better able to appreciate the responsibility of using human subjects in their studies if they are aware of the history of clinical research4. Throughout history, many doctors have faced with a lack of options for high-quality care. Jan Baptist van Helmont made an effort to make sure that therapies were being compared in the seventeenth century. According to Van Helmont, medical professionals have an obligation to identify therapies that are likely to benefit their patients while causing the least amount of harm. Dr. James Lind, a Scottish navy surgeon, carried out the first known planned clinical study around a century after Van Helmont's concept. Lind started researching scurvy, which killed thousands of British sailors every year, in 1747(4).

The Royal College of Physicians of Edinburgh established the James Lind Library in 2003 as an online tool for monitoring clinical trials. The biblical Daniel's clinical trial is the first clinical trial that has been documented, followed by China's in the eleventh century and France's in the sixteenth. However, the first person

to undertake a controlled clinical trial was likely the Edinburgh surgeon James Lind (1716–94), who looked into the best way to treat scurvy and is the source of the library's name. The first scientist of the contemporary period to conduct clinical studies on scurvy was Mr. Lind. There were many reports of clinical trials following the publication of this scurvy trial in 1753. Since 1950, there has been a consistent rise in the quantity of clinical trials published in publications that the US National Library of Medicine indexes. A growing number of comparative studies were conducted after Lind's work was enacted and published. Scientific logic and methods were used to address societal issues and give the public the advancement they needed.

Since 1950, there has been a consistent rise in the quantity of clinical trials published in publications that the US National Library of Medicine indexes(5).A growing number of comparative studies were conducted after Lind's work was enacted and published. Scientific logic and methods were used to address societal issues and give the public the advancement they needed.

The controversial Nuremberg trials in Germany, when Nazi doctors were convicted for crimes committed during human experiments on captives in concentration camps during World War II, led to the introduction of the Nuremberg Code in 1947. The Nuremberg Code, also known as the International Code of Medical Ethics, established the first fundamental principles of research ethics. These globally recognized standards were developed to punish doctors who had committed heinous crimes against humanity during World War II.

The statement stipulated that the advantages of research must exceed the dangers and that free participation was crucial. Even though the Nuremberg Code was widely reported and provided clear guidelines for investigators' duties, unethical research continued to occur for the next twenty years. Although ethical research was now widely accepted thanks to the Nuremberg Code, some researchers were still breaking it.

The Declaration of Helsinki is an international document that the World Medical Association wrote in 1964 to support informed consent and voluntary participation in research involving human subjects. Since then, it has undergone frequent revisions and now includes worldwide research ethics as well as guidelines for "research combined with medical care" and "non-therapeutic research."

The Belmont Report, written in 1979 by the National Commission for the Protection of Human Subjects in Biomedical and Behavioral Research (19), provided fundamental ethical standards and recommendations for using human subjects in research. These criteria are based on three fundamental principles: justice, beneficence, and respect for others. From trial-and-error to the current practices of stringent and thorough rules, clinical research has changed. Experimental controls, randomization, therapy comparison, placebo, and double-blind experimentation were used to overcome scientific obstacles.

The 20th century was undoubtedly characterized by significant shifts in medical practice, with new techniques for analyzing experimental designs being introduced all along the way. Standardized methods for evaluating the effectiveness of treatments and rules for safeguarding the patients involved were required as evidence-based practice emerged. Clinical trials must continue to develop in order to advance available medications and give current patients the best care possible. Standardized clinical trials have been shown throughout history to provide answers to questions that other methods of scientific inquiry are unable to.

Big data, pharmaceutical and device companies creating marketing trials, financial concerns, time constraints, and growing public health data are examples of contemporary challenges and opportunities for clinical research. However, in order to ensure the best possible clinical outcomes, research methods must be continuously improved. In particular, privacy issues and respect for individuals will be challenged by the sophisticated ability to collect and manipulate data. It is crucial that researchers keep in mind the rich history that brought us to this point as we move into a new era of clinical research(4).

Table 1: Comparison Between Traditional and Digital Clinical Trials

POINT	TRADITIONAL CT	DIGITAL CT
LOCATION	Performed at places like Hospitals physically	Performed online without physical presence
COLLECTION OF DATA	On site	Using digital tools
ENGAGEMENT OF PATIENTS	Only local people can participate	Global reach and can be performed by anyone
SURVEYING	On site	Remotely monitored
COST AND DURATION OF TRIAL	Higher and time-consuming	Lesser and quick

III.WHY CLINICAL TRIALS ARE GOING DIGITAL?

1.Earlier,in conventional clinical trials,the cost would go up to US$ 19 million but digitization of clinical trials has increased efficiency of all the processes including screening leading to reduction in the trial cost(5).

2.Traditional clinical trials are a real hectic for healthcare staff as they have to look into everything but digitizing can cause less burden to them. Also, numerous case report forms get difficult to screen and digitizing clinical trials can help as they contain automated mass screening(5).

3. There can be limitation during any pandemic or virus outbreak and thus clinical trials using a traditional method can be of a burden E.g. COVID -19 Pandemic . Therefore ,we can say that digitization of trials can be easier and efficient(6).

4.The digitization of clinical trials have allowed the investigators to modify the methodology of trials with real-world data collection process(6).

5. Use of many tools have lead to paperless as well as 'site-less' clinical trials that help patient to enroll for the trials comfortably making it hustle-free for healthcare staff as well as patients themselves(6).

IV.IMPORTANT TOOLS USED IN CLINICAL TRIALS THAT HELP DIGITIZING

The emergence of wearable technologies and digital health solutions has opened up new avenues for biopharmaceutical research and development. These technologies include wearable, implantable, ingestible, and external devices or sensors, as well as digital mobile health applications (apps) that users can access through their own electronic devices (such as computers, tablets, and smartphones). These items and their capabilities can develop and grow as technology advances, opening up more possibilities for use in healthcare delivery settings. Digital technology integration in clinical trials, in particular, has enormous potential to change the conventional method of drug research and development at various phases of a product's lifespan.

The usefulness of incorporating various digital platforms into clinical trials is being investigated by a number of pharmaceutical companies, academic institutions, technological start-ups, government bodies, and others(7).

Following are the tools used:

1] EMBRACE -EMBRACE WATCH AND MATE DIGITAL HEALTH APP :- This watch is made for epilepsy patients that need a track record of seizures. It keeps record of the seizures on 24/7 basis.

2] ITEREX-MACHINE LEARNING PRODUCTIVE MODEL WIH PATIEND DECISION SUPPORT AND COPD TRACKING ALGORITHM:- After creating a medical profile on the app, the patient answers all the questions asked by the app. Followed by this, the app suggests if the patient should continue the treatment, go to emergency department or to contact the physician.

3]PhysIQ- AccelerateIQ Platform app :- It is a patient monitoring system with wireless technology that includes smartphone app for data analysis. It is an option for continuous monitoring of health of patients suffering from COPD.

4]HEXOSKIN-WEARABLE TEXTILE WITH SENSORS:- It was designed to collect the overnight data of patients suffering from COPD. It includes cardiac activity, respiratory activity, and sleep activity(7).

V.VIRTUAL CLINICAL TRIALS

A relatively new and underutilized approach to doing clinical research using online social interaction platforms and technologies (such as apps and electronic monitoring devices) is virtual clinical trials. VCTs are a modification of clinical trials that make them more affordable, time-efficient, and participant-friendly rather than a brand-new or distinct kind of clinical study. VCT is able to boost participant diversity and representation, improve retention, and recruit more quickly by utilizing digital health technologies. Additionally, compared to newspaper, radio, and television advertisements, running online campaigns offers the following advantages: flexibility because a campaign can be turned on or off at any time; proper tracking allows for the precise targeting of actual leads; and it may be more cost-effective with a lower cost per patient than traditional media.

METHODOLOGY:

Virtual clinical trials are conducted from a patient's home using technology and social media platforms. A patient-centric approach to clinical research is made possible by these electronic procedures. in order to avoid the participant having to travel to a clinical research facility. A wearable device (such as a phone, watch, or even glasses) connected to the clinical research study can be used by the individual to participate from home. These wearable sensors automatically provide data to the study's electronic data capture (EDC) record, including body temperature, blood glucose levels, Spo2, heart rate, and sleep cycle. In certain VCTs, the investigator goes to the subject's house to administer medication and conduct follow-up.

In certain VCTs, the investigator goes to the subject's house to administer medication and conduct follow-up. In order to conduct every phase of the clinical trial from the comfort of the patient's home, including recruitment, patient counseling, and the measurement of clinical endpoints and adverse reactions, these trials fully utilize technologies (apps, monitoring devices, etc.) and online social engagement platforms. Many contend that virtually conducted clinical trials present chances for a more patient-centered or centric approach because they rely on electronic processes.

Advantages of VCTs:

- The primary benefit is that the virtual trial design optimizes patient accessibility and study enrollment. Due to the fact that over 80% of clinical studies fail to reach their initial goals, patient recruitment and enrollment is frequently the longest stage of the process(1).
- They increase the range of individuals who can take part in the experiment; they also reduce the need for site infrastructure and staffing, which lowers trial expenses. By including a wider range of people, this improves trial accrual and increases the generalizability of the trial outcomes.
- Decentralized trial procedures are necessary to obtain real-world data on the effectiveness of therapies. Additionally, cutting-edge data collection techniques offer continuous real-time data as opposed to data at discrete intervals and enable earlier(8).

Challenges faced in conducting VCTs:

- The availability of technology, such as Internet connectivity and familiarity with web-based programs, is crucial for virtual trials. Certain participant groups may be excluded as a result(8).
- It can be difficult to transfer large amounts of sensitive health data over the internet, but this risk can be reduced to a manageable level with the right technologies and defense techniques, such as storing anonymized data on external web servers secured by ID and password, using secure web mails, and using web servers hosted by reliable providers. The recruited individuals' privacy needs to be protected(1).

- The data gathered from wearable sensors, mobile devices, and electronic health records must be reliable, accurate, and of high integrity. Some businesses employ two-way digital health technologies, such as data gathering via a smartphone app or a mobile device that collects data without the participant's personal input, by contacting participants to verify the correctness of the readings(1).
- Drug efficacy may be impacted by handling and storage conditions, and supply chain logistics are necessary for the remote delivery of research treatments(8).
- When using nearby labs or imaging facilities for study evaluations, quality control is crucial.

CONCLUSION:

Technology has made it possible to analyze trial data in new ways and produce additional evidence. These studies usually give participants access to research teams via Web-based portals, occasionally involve home visits, and gather data via surveys, networked medical devices and wearables, and other methods. This strategy has a lot of room to grow, despite the fact that there are undoubtedly complications because of the enormous volume of data produced, safety issues, and other factors. In conclusion, Phase II–IV trials have employed VCTs thus far. These experiments' outcomes have been encouraging. Additionally, it has been successful in achieving the pharmaceutical industry's objective of low risk and high return throughout clinical trials.

VI.CLINICAL DATA MANAGEMENT

An essential and pertinent component of a clinical study is clinical data management. Whether intentionally or inadvertently, all researchers engage in CDM activities while conducting their study. During our study activity, we carry out some of the CDM processes without defining the technical steps. The process of gathering, cleansing, and managing subject data in accordance with legal requirements is known as CDM. The main goal of CDM procedures is to produce high-quality data by collecting as much data as possible for analysis while minimizing errors and missing data. Best practices are used to guarantee that data are accurate, dependable, and complete in order to achieve this goal. The advent of software programs that keep an audit trail and make it simple to find and fix data inconsistencies has made this easier. CDM can now manage large trials and guarantee data quality even in difficult trials thanks to sophisticated advancements.

TOOLS FOR CDM:

Many software tools are available for data management and they are called Clinical data Management systems(CDMS). A CDMS is now necessary to manage the massive volume of data in multicentric trials. While some open source tools are also accessible, the majority of CDMS used in pharmaceutical companies are commercial. ORACLE CLINICAL, CLINTRIAL, MACRO, RAVE, and eClinical Suite are tools of CDM that are used. These software tools are essentially identical in terms of functionality, and neither system has any appreciable advantages over the other. These software programs are costly and require advanced IT infrastructure in order to operate. Furthermore, numerous global pharmaceutical behemoths employ specially designed CDMS instruments to meet their operating requirements and protocols. OpenClinica, openCDMS, TrialDB, and PhOSCo are the most well-known open source tools(9).

GUIDELINES AND STANDARDS FOR CDM:

The Good Clinical Data Management Practices (GCDMP) guidelines, which outline the principles of good practice in CDM, are published by the Society for Clinical Data Management (SCDM). Since its first publication in September 2000, GCDMP has undergone a number of changes. The GCDMP document that is now in use is the July 2009 edition. GCDMP offers guidelines for recognized CDM practices that comply with legal requirements. It covers the CDM process in 20 chapters, emphasizing best practices and minimum standards.

A multidisciplinary nonprofit group called the Clinical Data Interchange guidelines Consortium (CDISC) has created guidelines to facilitate the collection, sharing, submission, and archiving of clinical research data and information. The data that has been entered is called metadata. This comprises information on the person who entered or modified the clinical data, the time and date of the input or modification, and specifics of the modifications.

THE CDM PROCESS:
Similar to a clinical experiment, the CDM procedure starts with the goal in mind. This indicates that the deliverable is taken into consideration throughout the entire process. The CDM process is intended to produce an error-free, legitimate, and statistically sound database, just as a clinical trial is intended to address the research issue. The CDM process begins early, even before the study protocol is finalized, in order to achieve this goal(9).

LIST OF CDM ACTIVITIES:

1] Data collection: Data collection is done using the CRF that may live in the form of a paper or an electronic interpretation. The traditional system is to employ paper CRFs to collect the data responses, which are re-stated to the database by means of data entry done in - house.

2] CRF Tracking: The traditional method collects data responses via paper CRFs, which are then manually input into the database.

3] Data Entry: Data entry is done in accordance with the DMP's accompanying rules. This only applies to paper CRFs that are obtained from the locations. Typically, two operators enter the data independently, a process known as double data entry.

4] Medical Coding: Medical terminology related to the clinical trial can be found and appropriately categorized with the use of medical coding. This task requires a fundamental awareness of the pathogenic processes involved, as well as knowledge of medical terminology, disease entities, and medications. Functionally, it also necessitates familiarity with the hierarchy of classifications found in electronic medical dictionaries as well as their organization. The available medical dictionaries are used to code adverse events that occur during the trial, prior to and concurrently provided drugs, and pre- or co-existing conditions. Adverse events and other illnesses are typically coded using the Medical Dictionary for Regulatory Activities (MedDRA), whereas drugs are coded using the World Health Organization-Drug Dictionary Enhanced (WHO-DDE).

5] Data Validation: Testing the veracity of data in compliance with protocol criteria is known as data validation.

6] Discrepancy Management: Another name for this is query resolution. Reviewing inconsistencies, looking into the cause, and either resolving them with documentation or declaring them unresolvable are all part of discrepancy management. Discrepancy management collects sufficient proof for data variances and aids in data cleaning. Nearly every CDMS has a discrepancy database where all discrepancies are noted and kept along with an audit trail(9).

ROLES AND RESPONSIBILITIES OF CDM:
Members of a CDM team are assigned various tasks and duties. A degree in biological science and familiarity with computer programs should be the minimal educational prerequisites for a CDM team member. Medical graduates should ideally work as medical coders. Nonetheless, paramedical graduates are also hired by the industry as medical coders. Every CDM team needs a few crucial roles. The list of roles given below can be considered as minimum requirements for a CDM team:
• Data Manager
• Database Programmer/Designer
• Medical Coder
• Clinical Data Coordinator
• Quality Control Associate
• Data Entry Associate

CONCLUSION:
The need for pharmaceutical companies to expedite the medication development process and for regulatory bodies to establish quality systems to guarantee the production of high-quality data for precise drug evaluation has led to the evolution of CDM. There is a slow transition from paper-based to electronic data management

systems in order to match expectations. Driven by technical advancements and corporate demands, CDM is maturing into a standard-based clinical research institution by finding a balance between the restrictions and expectations of the current systems(9).

VII.IMPACT OF COVID-19 ON CLINICAL TRIALS

Our lives have been completely upended by the coronavirus disease 2019 (COVID-19) pandemic, which has killed thousands of people worldwide and infected millions more. One The suggested tactic to slow the virus's transmission and lessen its fatal consequences is social separation. This has led to serious problems in day-to-day living and put a strain on health care systems by requiring more ventilators, personal protective equipment, diagnostic testing, and healthy personnel. Clinical trials face numerous challenges during the pandemic, including shortages of medical and support personnel, insufficient monitoring, travel restrictions, disruptions in supply chains for products under investigation, shortages of medical equipment and personal protective equipment, uncertainty about ongoing funding, and limitations imposed by sponsoring institutions(10).

Funding is crucial for starting a new clinical study or even continuing an ongoing one in order to see it through to completion. In addition to competing for funds during COVID-19, clinical trials also had to deal with lockdown laws that made it nearly impossible for research subjects to participate. Every participant impacted by a COVID-19-related research disruption should have a unique participant identity and an explanation of how their participation was changed. If participants are unable to visit research venues as specified in the study protocol, the researchers may need to determine whether alternative safety assessment procedures are viable.

Other approaches could involve phone calls, telemedicine for virtual visits, or other locations for treatment or data collection.

When it comes to alternative monitoring, meticulous documentation will be needed to determine why, how, and what data was gathered, as well as who supplied the information and how and why the information sources were confirmed. Faster communication is necessary during health emergencies in order to analyze the risks and benefits of COVID-19 actions. With encrypted communication to safeguard data integrity, virtual meetings may make this feasible.

Numerous public health initiatives brought about by the COVID-19 epidemic have severely damaged many nations' healthcare systems. In terms of clinical trials, this circumstance has a significant impact on study participants, healthcare professionals, researchers, trial sponsors, and research organizations. The trial sites are significantly impacted by this pandemic because they find it difficult to carry out trial operations, which ultimately impedes trial progress and causes delays in research deadlines. Managers will be able to support trial sites with adaptability and creativity if they adopt new strategies and comprehend the important risk indicators. For example, using telemedicine to communicate with patients and replacing patient site visits with new-trial virtualisation will help manage ongoing clinical trials and be advantageous for the post-pandemic era (11).

VIII.CASE STUDY/EXAMPLE

The research team used the Internet to recruit participants, used web-based questionnaires to screen them for eligibility, conducted laboratory testing at community facilities, and used electronic diaries to keep track of initial run-in data. Local doctors conducted physical examinations. The doctor obtained an informed consent countersignature via an interactive web-based procedure. The trial participants received their prescription drugs directly.

The VERKKO trial evaluated the use of a patient-centric online clinical trial platform combined with a wireless blood glucose meter in a virtual clinical trial scenario. It was a Phase IV clinical trial including individuals with diabetes.There was no site visitation involved in the study. Through social media marketing, the participants were asked to self-register their interest in an online system, and the study team examined their applications online. After reviewing electronically supplied patient data and digitally signing the informed permission form, a subset of participants received wireless glucose meters with 3G capability.

The device automatically transferred glucose readings into a digital application so that the study site and participants could review them in real time. This study's performance metrics were contrasted with those of a comparable protocol that was conducted as a conventional site-centric study. Better participant recruitment,

the ability to include older individuals, increased compliance, and high participant satisfaction were all demonstrated by the virtual trial. Additionally, the study site reported spending less time on activities related to study coordination. As a result, this virtual trial was beneficial for both the researchers and the participants(8).

IX.CHALLENGES AND LIMITATIONS

- Improving recruitment, participation, and diversity: The ability of DCTs to improve accessibility and broaden participant diversity is one of its main benefits. This opinion was shared by Goodson et al. and Nebie et al., who discussed how DCTs alleviate logistical challenges encountered in traditional trials, especially for people living in underserved or rural locations. 12, 14, 25 Huh et al.'s report that 26.7% of research participants came from non-metropolitan areas provides more proof of this improved accessibility. DCTs have the potential to make clinical trials more representative of diverse populations by reaching traditionally underserved populations. This could lead to more generalizable results and address long-standing issues of health disparities in medical research(13).
- Enhancing patient experience and engagement: Another important advantage of DCTs is the huge reduction of participant load. Reducing the requirement for in-person visits increases participant satisfaction and retention, according to Betcheva et al. and DiMasi et al. 8,21 High patient satisfaction with eICF and eDiary was reported by Sommer et al., indicating the beneficial effects of these digital tools on participant experience. DCTs improve overall trial participation and alleviate logistical restrictions by utilizing digital technologies. Higher retention rates and more thorough data collecting could emerge from this load reduction, potentially raising the general caliber and dependability of clinical trial findings.
- Increasing productivity and cost-effectiveness: DCTs provide more extensive financial advantages than just immediate cost reductions. DCTs improve resource efficiency and foster long-term sustainability in trial management, as noted by DiMasi et al. 21. Harmon et al. further pointed out that digital technology improves clinical trial participation and efficiency while offering useful real-world data. 17. According to their analysis, phase II and III durations were shortened by at least 10% and eNPV increased by $20 million per medicine. Additionally, they reported a particular cost savings of $507,600 for phase II trials as a result of fewer amendments and a drop in screen failure rates from 31.5% to 24.1%. The long-term financial advantages of DCTs are enormous, even though the initial investment in infrastructure and technology can be high. According to DiMasi et al., the ROI for DCTs is seven times higher than that of eNPV increments. 21. DCTs are a more practical choice for clinical research because of these budgetary benefits, particularly in environments with limited resources(13).
- Technological difficulties and the digital gap: The digital divide poses a serious problem, especially with regard to accessibility. DCTs may unintentionally exclude participants who do not have access to the required technology or reliable internet connections, as noted by Sehrawat et al. and Nebie et al. 12, 27 This restriction may make DCTs less inclusive, especially in environments with limited resources. Although eIRB, eSource, and clinical trial administration systems were widely adopted, wearables and online recruiting portals were utilized less frequently, according to Cummins et al., suggesting uneven technology acceptance among DCT applications. 22 Nebie et al. also brought attention to problems with technology usability, indicating the necessity for creative fixes to guarantee fair access. Innovative approaches will be needed to overcome this obstacle, such as giving participants access to technology or creating low-tech substitutes for data collecting in specific contexts. In order to guarantee that DCTs actually increase participant diversity rather than restrict it, future research should concentrate on methods to close this digital gap.
- Regulatory challenges: Implementing DCTs is made more difficult by regulatory obstacles. Regional differences in regulatory frameworks add to the variety in study results. To guarantee uniformity in the application and interpretation of results across various countries, harmonized regulatory guidance on DCTs is required. In addition to facilitating multinational trials, the creation of globally accepted DCT standards may hasten the implementation of novel trial designs worldwide(13).
- Ethical complications: In the case of DCTs, ethical issues also come up. Petrini et al. emphasized how difficult it can be to get informed permission in decentralized settings, which may jeopardize participant comprehension. In order to lessen this problem, Pascalev emphasized the significance of offering a transparent, participant-friendly consent procedure. 24. Furthermore, it is important to carefully assess and address the possibility

that DCTs could worsen already-existing health inequities because of unequal access to technology. The creation of a transparent, participant-friendly consent procedure for decentralized settings may establish new benchmarks for moral behavior in clinical studies(13).

X.FUTURE DIRECTIONS

1]DECENTRALIZED CLINICAL TRIALS(DCTs):
One of the most promising developments for clinical trials in the future is decentralized clinical trials. DCTs use wearable technology, mobile apps, telemedicine, and other digital health technologies to conduct studies remotely, frequently removing the need for patients to travel to central trial locations. In addition to increasing patient comfort, this strategy may be able to reach a wider range of people, including those who live in underserved or rural locations. Because DCTs enable ongoing patient monitoring in their natural settings, they are especially well-suited for managing chronic diseases. The ability to monitor health parameters and modify treatment regimens in response is improved by real-time data collecting using wearable technology and smartphone apps. DCTs can speed up the clinical trial process by increasing patient enrollment and retention while lowering expenses and logistical obstacles.

2]AI IN CLINICAL TRIALS:
Artificial intelligence is rapidly transforming clinical research by enabling faster and more accurate data analysis, optimizing trial designs, and predicting patient outcomes. AI can help identify potential candidates for trials by analyzing vast datasets, such as Electronic Health Records (EHRs), and selecting participants based on specific genetic or clinical criteria. This process, known as "precision recruitment," improves the likelihood of identifying patients who will benefit most from the intervention being tested. AI can be extremely useful not only for recruiting but also for real-time analysis of trial data, pattern recognition, and treatment response or adverse event prediction. By recommending which variables to test, figuring out the best dosage, or identifying patient subgroups that could react better to particular therapies, machine learning algorithms can also optimize trial designs. Clinical trials can be streamlined and made more economical and efficient with the aid of AI-powered solutions.

3]ADAPTIVE TRIALS:
Adaptive trials are a cutting-edge method of designing clinical studies that permit protocol changes depending on interim data analysis. Because of this flexibility, researchers can make real-time modifications to the study, such as adjusting the treatment dose, modifying the patient population, or stopping the trial if the medication exhibits an undesirable safety profile or insufficient efficacy. By lowering the number of patients required to derive reliable findings, the adaptive trial model not only expedites but also improves the efficiency of clinical trials. This strategy is particularly helpful in specialties like oncology, where patient outcomes might differ greatly from treatment to treatment. Adaptive trials have the potential to reduce development times and expedite the release of novel treatments by enabling researchers to modify the trial in response to preliminary findings(13).

4] PATIENT-CENTRED TRIALS:
Clinical trials in the future will prioritize patient-centered treatment, in which patients actively participate in the planning and conduct of the trials. By giving patients' needs and preferences top priority, this method guarantees that trials are created with their welfare in mind. Future research will heavily emphasize personalized medicine, which customizes therapies to each patient's unique genetic, environmental, and lifestyle characteristics. Additionally, telemedicine and mobile health apps can improve patient engagement during the experiment. Patient-centered trials will boost patient retention rates and build better trust in the clinical trial process by incorporating patient feedback, guaranteeing greater openness, and offering more flexible participation options(13).

5]REGULATORY EVOLUTION AND DIGITAL PLATFORMS:
Regulations will need to change to allow for new approaches as clinical trials become more sophisticated and technologically advanced. The emergence of DCTs, adaptive trials, and AI in clinical research is already causing regulatory agencies like the European Medicines Agency (EMA) and the U.S. Food and Drug Administration (FDA) to adjust. Clinical trials will also depend more and more on digital platforms that facilitate

data sharing, electronic informed consent, and remote monitoring. These technologies can provide more effective data administration, enhance trial oversight, and simplify regulatory compliance. Blockchain technology may also improve data security and integrity by guaranteeing transparent, verifiable, and impenetrable trial data(13).

XI.CONCLUSION

Clinical trials have a promising future thanks to technological advancements that will make them more effective, patient-friendly, and inclusive. Clinical research is about to undergo a revolution thanks to decentralized trials, AI-driven recruitment and data analysis, adaptive designs, and a greater focus on patient-centered care. These developments have the potential to speed up the creation of novel therapies, enhance patient outcomes, and lower clinical trial expenses. It is evident that ongoing cooperation between researchers, patients, regulators, and technology developers will influence the direction of clinical trials in the future. The next generation of clinical trials has the potential to completely change how we think about medical research and treatment if they continue to innovate and prioritize patient needs.

XII.REFERENCES

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