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# Editorial

Dear Readers

**Season's Greetings & A Very Happy New Year 2026 To All**

Please find the December 2025 issue of "**Subharti Journal of Interdisciplinary Research**" an online publication of our prestigious Swami Vivekanand Subharti University.

It is with deep sense of indebtedness that I thank the Management, Hon'ble Vice Chancellor, CEO, EO and all the Deans/Heads of Institutes and Research contributors, who have unreservedly extended assistance towards the online publication of the journal since the December 2018 issue. As an editor-in-chief of our prestigious publication I deem my role to be that of catering to the needs of knowledge producers while at the same time upholding the academic integrity of the journal. My editorial plan includes moving the journal forward by increasing the impact and circulation of the journal. We together must envision the research coming both from senior scholars as well as emerging scholars. It is the need of the hour to diversify our attention and look forward in the direction that enables us to be future ready.

The journal, due to everyone's dedicated efforts is growing and is receiving citations across various platforms from researchers irrespective of the borders. The authors have provided their treasured work for publication and it has been an abiding and inspiring experience to go through their work. We are working hard to get submissions from outside the University too and sincerely seek everyone's support for that. If possible, please include the worthy authors who are working on the similar topics from other universities while submitting your research work for publication. This will foster many valuable partnerships and will have an everlasting effect on the viewership of the journal. The editorial team is dedicated to improve the quality of the research work being published and secure the indexing for the journal in the near future.

I hope that this issue of the journal will be up to the expectations of our readers and patrons and our team is looking forward to any and every beneficial contribution on streamlining our publication process. I once again seek your support and look forward to welcoming your submissions for next issue and your valuable suggestions are eagerly awaited.

Happy Reading

Dr Vijay Wadhwan

**Editor-in-Chief**

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Review Article

# Pharmacovigilance in the Era of Modern Medicine: Surveillance, Alerts and Black Box Warnings

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**Abstract:**

**Background:** Pharmacovigilance (PV) is a critical public health discipline focused on the detection, evaluation, and prevention of adverse drug reactions (ADRs) and other drug-related problems. Its significance has intensified in the modern era, with increasing drug complexity, widespread use of biologics, and expanding post-marketing surveillance needs. **Objective:** To review the current landscape of pharmacovigilance, highlight recent drug safety alerts and black box warnings, and assess the integration of pharmacovigilance systems in India, with a regional focus on activities in Meerut. **Methods:** This article presents a narrative review of pharmacovigilance practices and regulatory alerts. It includes recent safety data from national and international authorities such as WHO, US-FDA, EMA, and India's IPC. Data on drug safety alerts (2024–2025) and black box warnings were compiled and analyzed to demonstrate real-world pharmacovigilance activity. **Results:** Multiple drug safety alerts were issued by IPC in 2024–2025, identifying severe ADRs like AGEP, DRESS syndrome, and leukopenia linked to commonly prescribed drugs. Black box warnings from the US-FDA were also reviewed, involving high-risk drugs. India's PvPI and MvPI have strengthened national vigilance, with Subharti Medical College serving as a key ADR monitoring center in western Uttar Pradesh. **Conclusion:** Pharmacovigilance remains vital in ensuring patient safety amid evolving therapeutic landscapes. Strengthening global and national surveillance, rapid dissemination of drug alerts, and promoting healthcare professional education are essential for minimizing drug-related risks and enhancing clinical outcomes.

**Keywords:** Pharmacovigilance, Adverse Drug Reactions, Black Box Warning, Drug Safety Alerts, PvPI, MvPI, Subharti Medical College, FDA, IPC, Patient Safety.

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Pharmacovigilance (PV) is the science and activities concerned with the detection, assessment, understanding, and prevention of adverse effects or any other drug-related problems.[1]It serves as a key component in ensuring drug safety throughout a product's life cycle—from pre-marketing clinical trials to post-marketing surveillance. With the global expansion of the pharmaceutical industry and the increasing complexity of drug therapies, the role of pharmacovigilance has become more crucial than ever. [1;2]

The **primary objective** of pharmacovigilance is to improve patient care and safety in relation to the use of medicines and to support public health programs by providing reliable, balanced information for the effective assessment of the risk-benefit profile of drugs. [1;2]

Adverse drug reactions (ADRs) and medication errors are among the leading causes of morbidity and mortality worldwide. Hence, a robust pharmacovigilance system helps in minimizing risks, promoting rational drug use, and enhancing therapeutic outcomes. [2,3]

Global organizations such as the World Health Organization (WHO), European Medicines Agency (EMA), and national regulatory authorities have emphasized the integration of pharmacovigilance practices into healthcare systems. [1,2] In India, **the Pharmacovigilance Programme of India (PvPI),** launched by the Ministry of Health and Family Welfare, plays a pivotal role in collecting and analyzing ADR reports to ensure patient safety and strengthen drug regulation.[4]

As healthcare continues to evolve with advancements in biotechnology, personalized medicine, and the use of artificial intelligence in healthcare, pharmacovigilance must adapt accordingly. This article explores the principles, current practices, challenges, and future directions in pharmacovigilance, highlighting its indispensable role in modern therapeutics.

**Pharmacovigilance and its impact in medicine**

Pharmacovigilance began globally after the thalidomide tragedy in the 1960s, which caused severe birth defects and highlighted the need for drug safety monitoring. In response, the World Health Organization (WHO) launched the International Drug Monitoring Programme in 1968, with VigiBase as the global ADR database.

In India, pharmacovigilance officially began in 2004 with the launch of the National Pharmacovigilance Programme (NPvP), later renamed as the Pharmacovigilance Programme of India (PvPI). The National coordination centre (NCC) for the PvPI is

the Indian Pharmacopoeia Commission (IPC), located in Ghaziabad, Uttar Pradesh.

In Meerut, the Pharmacovigilance Adverse Drug Reaction (ADR) Monitoring Centre (AMC) is in Pharmacology Department, Netaji Subhash Chandra Bose Subharti Medical College, affiliated with Swami Vivekanand Subharti University. We report adverse drug events received from LLRM Medical college and reports filled by healthcare personnels of hospitals of NCR.

Since 24 January 2014 the institution has played an active role in promoting drug safety and awareness, and it also offers a certificate course in the basics of Pharmacovigilance and Materiovigilance, reflecting its commitment to strengthening pharmacovigilance practices in the region.

Materiovigilance is a system for monitoring and preventing adverse events related to the use of medical devices. It involves identifying, collecting, reporting, and analyzing any untoward occurrences associated with medical devices, with the goal of improving patient safety and preventing future incidents. [5]

The MateriovigilanceProgramme of India (MvPI) was formally launched at the Indian Pharmacopeia Commission (IPC), Ghaziabad by the Drugs Controller General India (DCGI) on July 06, 2015. Indian Pharmacopoeia Commission (IPC) is an autonomous institution of the Ministry of Health & Family welfare and also functions as the National Coordination Centre (NCC) for the MateriovigilanceProgramme of India. Sree Chitra Tirunal Institute of Medical Sciences & Technology (SCTIMST), Thiruvananthapuram functions as a National Collaborating Centre for the MvPI. Technical support for the programme is being provided by Healthcare Technology Division, National Health System Resource Centre (NHSRC), New Delhi which is also a WHO collaborating Centre for priority medical devices and health technology policy.[5]

In Meerut since July 2021, the Medical Device Adverse Event Monitoring Centre (MDMC) is Department of Pharmacology, Netaji Subhash Chandra Bose Subharti Medical College, affiliated with Swami Vivekanand Subharti University.

Ensuring the safety of medications is a critical component of public health and clinical practice. Despite rigorous testing and regulatory approval processes, many drugs may exhibit unforeseen adverse effects once they are introduced to a broader patient population. **Drug safety alerts** play a pivotal role in identifying, communicating, and managing these post-marketing risks. These alerts are issued by national and international regulatory authorities—such as the World Health Organization (WHO), U.S. Food and Drug Administration (FDA), European Medicines Agency (EMA), and Central Drugs Standard Control Organization (CDSCO) in India—based on new safety data from pharmacovigilance systems, spontaneous reports, clinical studies, or epidemiological research. [6,7]

Drug safety alerts are designed to inform healthcare professionals, patients, and stakeholders about significant safety concerns, including new adverse drug reactions (ADRs), contraindications, drug–drug interactions, or product recalls. These alerts aim not only to minimize harm but also to reinforce the safe and effective use of medicines in clinical settings.

Table 1: Various drug safety alerts issued by IPC in year 2024 and 2025 [5]

| Month | Suspected Drug | Indication | ADR |
|---|---|---|---|
| **May 2024** | Meropenem | For treatment of pneumonia, nosocomial pneumonia, UTI, intra-abdominal infection, gynecological infection, skin & soft tissue infection, meningitis, septicemia & empiric treatment of presumed infection in adult patients with febrile neutropenia. | Acute Generalized Exanthematous Pustulosis (AGEP) |
| **June 2024** | Acetazolamide | As an adjunct in the treatment of Choroidal effusion chronic open-angle glaucoma; secondary glaucoma; as part of pre-operative treatment of acute-angle closure glaucoma. | Choroidal effusion or Choroidal detachment |
| **July 2024** | Vancomycin<br><br>Amlodipine | Treatment of serious infection due to Gram-positive cocci including methicillin-resistant staphylococcal infections, staphylococcal brain abscess, meningitis and septicemia.<br>To reduce fatal coronary heart disease and non-fatal myocardial infarction, and to reduce the risk of stroke. To reduce the risk of coronary revascularization procedures and need for hospitalization due to angina in patients with coronary artery diseases | Drug Reaction with Eosinophilia and Systemic Symptoms (DRESS) Syndrome.<br><br>Lichenoid Keratosi |
| **August 2024** | Metronidazole | For the treatment of amoebiasis, urogenital trichomoniasis & giardiasis | Fixed Drug Eruption (FDE) |

| | | | |
|---|---|---|---|
| **September 2024** | Tetracycline | Treatment of Rocky Mountain spotted fever, typhus, Q fever, rickettsial pox, tick fever caused by Rickettsiae, respiratory tract infections caused by Mycoplasma pneumonia, Chlamydia infection, nongonococcal urethritis, chancroid, plague, tularemia, cholera, brucellosis, bartonellosis, granuloma inguinale, haemophilus and kleibsella infections, psittacosis. | Fixed Drug Eruption |
| **Nov 2024** | Amphotericin B<br><br>Carbimazole | 1. Treatment of Febrile Neutropenia in cancer patients.<br>2. Treatment for invasive fungal infection inpatients, who are refractory to or intolerant conventional Amphotericin of therapy.<br>3. Indicated for the treatment of Visceral Leishmaniasis.<br><br>Indicated for the treatment of thyrotoxicosis including thyrotoxicosis crisis. | Hyperkalaemia<br><br>Agranulocytosis |
| **Dec 2024** | Beta-blockers (Metoprolol, Propranolol, Atenolol) | **Metoprolol:** For the treatment of essential hypertension in adults, functional heart disorders, migraine prophylaxis, cardiac arrhythmias, prevention of cardiac death and reinfarction after the acute phase of myocardial infarction,stable symptomatic CHF and angina pectoris.<br>**Propranolol:** For the treatment of cardiac arrhythmias ; tachycardia; hypertrophic obstructive cardiac myopathy ;pheochromocytoma; thrombosis; management of angina; essential and renal hypertension; prophylaxis of migraine.<br>**Atenolol:** For the treatment of hypertension, angina pectoris, cardiac arrhythmias. | Hypokalemia |
| **March 2025** | Metronidazole<br><br>Luliconazole<br><br>Dalteparin<br><br>Gliclazide<br><br>Tramadol | For the treatment of amoebiasis, urogenital trichomoniasis & giardiasis.<br><br>For the treatment of cutaneous mycosis viz. Tinea pedis, Tinea corporis and Tinea cruris.<br><br>For the extended treatment of symptomatic VenousThromboembolism(VTE) proximal Deep Vein Thrombosis(DVT) and/or Pulmonary Embolism (PE) to reduce the recurrence of VTE in patients with cancer.<br><br>Indicated for the treatment of all types of maturity onset diabetes, diabetes without or with obesity in adults.<br><br>For the treatment of severe acute and chronic pain, diagnostic measures and surgical pain. | Acute Generalised Exanthematous Pustulosis (AGEP)<br>Chloasma/Melasma<br><br>Muscle spasms<br><br>Erythema multiforme<br>Fixed Drug Eruption |
| **May 2025** | Sulfamethoxazole + Trimethoprim | For the treatment of Urinary Tract infection; Respiratory-tract infection including Bronchitis, Pneumonia, infections in Cystic Fibrosis, Melioidosis, Listeriosis, Brucellosis, Granuloma Inguinale, Otitis Media, Skin infection, Pneumocystis Carinii Pneumonia | Leukopenia |

**A Black Box Warning**

They are most serious alert issued by the U.S. FDA. Are used to highlight drugs that carry a significant risk of severe or life-threatening adverse effects. Displayed with a bold black border in the drug's prescribing information, it serves as a clear warning to prescribers and patients. [2,7]

While such drugs may offer important therapeutic benefits, they require extra caution, monitoring, and informed decision-making

.

**Table 2: Drugs which have been issued black box warning recently**

| S.No | Drug Name | Warning |
|---|---|---|
| 1 | CAR-T Therapies (e.g., Abecma, Carvykti, Tecartus) | Risk of secondary malignancies |
| 2 | Prolia (denosumab) | Severe hypocalcemia in CKD patients |
| 3 | Ocaliva (obeticholic acid) | Serious liver injury (especially without cirrhosis) |
| 4 | Veozah (fezolinetant) | Rare serious liver toxicity |
| 5 | Glatiramer acetate (Copaxone, Glatopa) | Risk of anaphylaxis |
| 6 | Trikafta (elexacaftor/tezacaftor/ivacaftor) | Serious and fatal liver injury |
| 7 | Fenfluramine | Cardiopulmonary risks |
| 8 | Lamotrigine | Neonatal withdrawal, drug reaction with eosinophilia |
| 9 | Gabapentin, Pregabalin | Interaction with hormones, withdrawal symptoms |
| 10 | Zenocutuzumab (Bizengri) | Embryo-fetal toxicity |

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**Conflict of interest: Nil**
**Acknowledgement: None**

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Review Article

# The Cricketer's Performance Analysis in the Key of Mathematical and Statistical Terms

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**Abstract:**

In This Paper is aimed primarily at the selectors of top-level cricket teams. An attempt is made to keep the statistics involve simple as possible so that all levels of selectors may apply this methodology to their teams. the analysis of both batsman and bowler performance outputs has assumed random performance. This assumption needs to be clarified before further progress can be made. The initial thrust of the paper is the identification of what constitutes form. Form can be likened to autocorrelation, in that an individual displays patterns or trends in performance over time. Therefore we will find some of the key mathematical and statistical terms, explaining their significance and how they are applied in the context of cricketer performance analysis.

**Key words :** Sportsmanship, Aggregate, Autocorrelation, Commentators, Economy Index.

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## Introduction

Cricket is a game of numbers. The very core of the sport is entwined with numerical values that translate ultimately to a match result. These sport statistics are a natural by-product of competitive sport and have been around along as contested sport has existed. Currently sport reporters and commentators bombard observers with a vast array of numerical values designed to describe an individual's performance at a particular skill. These added extras contribute to the entertainment value of professional sport. However, is this information of use to coaches and selectors of cricket teams?


Figure No.:01

This paper is aimed primarily at the selectors of top-level cricket teams. An attempt is made to keep the statistics involve simple as possible so that all levels of selectors may apply this methodology to their teams.

There are several key reasons for measuring and evaluating performance in team sport. Organisational Behaviour Theory proves particularly useful in drawing together sport statistics and selection. According to Greenberg and Baron (1997) to build high performance teams appropriate performance measures are required.

## General Overview of Cricket Statistics

Cricket statistics are meticulously collated ball by ball. The vocabulary of the game continually refers to abstract statistical concepts such as average, aggregate and form - without divulging the secrets of what these mystical values contain. For the sake of simplicity, all values involved are reduced to one dimension. However, this leaves the cricket observer to assume and speculate as to the base values involved. The written media has recently taken to describing bowling performance by listing the number of wickets taken followed by the bowler's average.


Figure No.:02

This form is limited; the basis behind this statement is discussed later in the evolution of the bowling indices.

In recent times, an increasing number of studies.: have been undertaken to understand the statistical

processes at work in the game of cricket. G.H. Wood and W.P. Elderton started the ball rolling in 1945, analysing individual batsmen in an attempt to find a general model that would describe individual scores. This is in accordance with the general trend, where most work to date has revolved around batsmen. This seems like an apparent contradiction, as the first skill taught to junior cricketers is how to bowl, for without bowlers the game cannot be played. However, with advent of one-day cricket and now Cricket Max, both geared towards
entertainment, the game is becoming increasingly batsmen orientated. "Batsmen have always received the highest accolades. Most histories of cricket are written around them, with the bolwers regarded merely as a necessary evil." (Nigel Smith, 1994, p.177). The reasoning behind the domination of batsmen in statistical papers may be due to the perceived ease of evaluation.

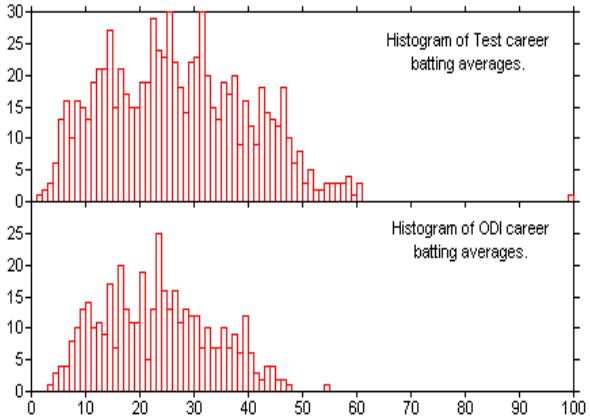

Figure No.:03

This leads to the definition of the statistics utilised in analysis of player performance, enabling a better understanding of the statistics involved.
Sport Statistics can be separated into two broad categories; Performance Indicators and Performance Outputs. A Performance Indicator is a quantitative measure that indicates individual performance in a particular facet of the game. These values are collated during the game in progress. Effectively, the game is dissected into small manageable slices, such that a numerical value can be assigned as a descriptive measure. An example of a Performance Indicator, associated with fielding performance, is Ground Ball Efficiency, defined as the number of times the ball isfielded cleanly divided bt the total number of times fielded. These values do not have a direct impact on the match figures.

Ground ball efficiency =

$$\frac{\text{no.of times the ball is fielded cleanly}}{\text{Total number of times fielded}}.$$

In contrast a Performance Output is a numerical expression detailing the direct result of participation in an event. For cricket these are summary measures detailed in a score book at the completion of an innings, such as score, wickets taken, overs bowled and so forth. As a consequence these values have a direct impact on the match figures-3 It stands to reason that these two categories are related in some manner. However, only performance outputs will be examined in this study, due to the ease of data collection and availability. Investigating the possible relationship between performance indicators and performance outputs will be analysed in future research. Statistically, assessing the performance of a batsman is relatively simple, as this can be given by a single variable, either runs scored in an innings, aggregate, average, or average contribution.
'Aggregate' refers to the total number of runs scored by the individual over a specified period of time. A player's 'Average' is then calculated by dividing the aggregate by the number of times the individual was dismissed during the specified time. 'Contribution' is the percentage of runs the individual provides the team total in an innings. Each value on its own can effectively describe performance.
Ideally, two dimensions need to be considered, one involving the players attacking ability, the other involving the ability to restrict runs. Kimber ( 1993) gives a graphical method for comparing bowlers. This utilises two dimensions; the attacking ability (strike rate) and the ability to restrict runs (economy rate). Bracewell (1998) proposed two independent normally distributed indices, based upon strike rate and economy rate, to describe performance. The first index deals with a bowler's ability to take wickets, the second with the ability to restrict runs. Both indices are evaluated using simple variations of formula that are already used, taken relative to the team performance.
The section dealing with assessing bowlers relies heavily on these indices. Having defined the performance outputs to be assessed it is necessary to discuss the relevance in a selection situation.

**Selection Framework**

With the wealth and quality of data available in cricket, it makes sense to utilise this quantitative information in the selection of individuals to maximise the formation of a collective unit (the team). The main assumption underpinning the work in this paper is that a player's natural ability is expressed by individual performance outputs collated following the completion of a match.
Statistics are not the only factors considered when selecting a team. However, Former New Zealand Coach Glenn Turner (1998) discusses the importance of statistics in choosing players in his book Lifting the Covers. In particular the second chapter reveals the emphasis placed on statistics in comparing and selecting individuals. In this instance it is used particularly to justify the non-selection of players, (Andrew Jones and Ken Rutherford) then to defend the selection of Lee Germon.
Since statistics are used to make and confirm selection decisions it is necessary to attempt to understand the nature of the data being generated by participation in sport. A greater understanding leads directly to better implementation and hopefully a competitive edge, for the selected team.

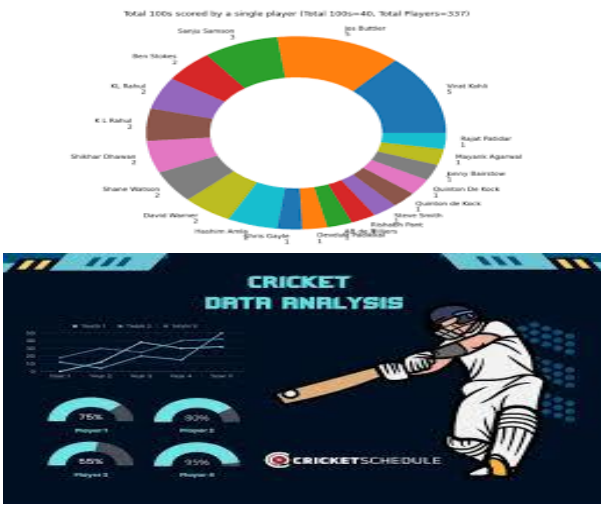


Figure No.:04

Former Australian captain, Richie Benaud, remarked on the simplistic nature of selection and the use of statistics stating, "All acaptain needs is the confidence that his bowlers are each capable of taking five wickets in an innings, his batsmen are capable of scoring a century and that everyone can field like Viv Richards (Benaud, 1995)." Obviously the captain deals with the players on the field and is not responsible for those selected to take the field, this lies in the hands of the selectors. The captain must believe that he has been given the best men to compete It then begomes the job of the selectors to ensure that the best combination of players available takes the field. If statistics are to be used in the selection process they must be meaningful, and secondly they must be used in an appropriate manner. This means that a relevant application of statistical methodology is that of monitoring individual ability.

**The Application of Quality Control to Cricket**

The idea of monitoring performance is as useful to the selector and the player as it is to the arm chair critic. An ideal method for monitoring an individual's performance is with control charts. The control chart is a useful tool in statistical process control. First developed by W.A Shewhart, the shewhart charts are widely accepted as standard tools for monitoring process of univariate independent and nearly normal measurements (Liu & Tang, 1996) Control charts have found frequent appiications in both manufacturing and non-manufacturing settings (Montgomery, 1997). With slight adjustments shewhart charts can be applied to cricket.

Provided the measurements of the individual's performance are reflective of quality, function, or performance then the nature of the 'thing' being measured has no bearing on the general applicability of control charts (Montgomery, 1997).

Montgomery (1997) discloses several reasons for the popularity of control charts. At least 3 draw direct parallels to cricket. Possibly most important is that control charts provide diagnostic information. This can identify flaws in technique, or the tendency for a player to struggle under certain conditions. Also control charts are proven at improving productivity, which translates to pushing a player and not allowing complacency.

In Cricket we are interested in selecting individuals that will maximise team performa~ce and ensure the best chance of victory. Whilst Cricket is a team sport, the nature of the game allows for individual aspects to stand out. Indeed, when we look at the possible selection of an individual, it is the performance outputs of the individual that is of primary concern. Therefore to ensure the right selections are made, it is important the right statistics are used.

Due to the awkward nature of bowling performance outputs, this leads to the evolution of the bowling indices.

These two independent, random, standard normal indices are a simple and effective way of allowing bowling performance to be measured from the post match statistics. They are more useful than the current convention used in the written media of quoting the number of wickets taken and the bowling average of an individual.

Utilising the assumption that an individual's worth is expressed via performance outputs, this thesis seeks to describe and understand the underlying statistical processes that shape our impression of player performance in the second chapter. Randomness is tested for and then distributional properties of the data are sought.

**Major Contributions of this Study**

It is expected that two extremes may exist, either form exists, or performance is random. If autocorrelation is present, then form exists. Intuitively performance would be considered random, due to the apparent lack of predictability of such a sport. "Uncertainty plays a large role in sports, and one can argue that the uncertainty associated with sports outcomes is one reason that sports are so popular (Stern, 1997, p19)." It has been shown that baseball is a game of chance (Cook, 19]7). An analysis of team tactics as related to the game of baseball and analysis of the annual World Series competition revealed that results were subject more to the laws of chance than the relative calibre of the competing teams. Taking a simplistic view of competitive sports suggests this may also be the case in cricket (Assuming everyone is equally able to compete, and that natural ability will differ, dependent on the pool of talent available). Logistically it would be ideal if performance is random. If this is the case then it is a relatively simple task to select the best individuals, provided that the sampling distributions to which the data belong are known.

In order to fully understand the summary statistics presented, and make effective use of the available information, the statistical distribution for each of the performance outputs needs to be known. Fulfilment of this requirement and that of randomness satisfies the most important assumptions regarding inference and quality control.

Bowling Performance for Individual Bowlers Of the individual disciplines, bowling is perhaps the hardest to evaluate quantitatively. A typical bowling analysis consists of four variables, Runs conceded. Maidens bowled, Overs bowled and Wickets taken. There is no easy way of interpreting these values independently. History plays a large part of how

these statistics are perceived as does the game situation. This section briefly reviews the statistical methods for evaluating an individual's bowling performance.

Kimber (1993) proposed a two-dimensional graphical display for comparing bowlers in cricket based on strike rate (SR) and economy rate (ER), taking advantage of the relationship that these two values have with the Bowling Average (AV). SrxER=100AV These values are traditionally calculated as follows the Economy Rate (ER) is defined as the runs conceded per ball.

However, this relationship does not take into consideration the team situation, and other confounding variables that confront a bowler, such as the state of the game, combined with environmental factors, as these can have an impact on how the specific individual's involved, batsman and bowler, approach each delivery. As a brief example, a batsman 1s more likely to attack the bowler towards the end of the innings, with wickets remaining in a run chasethan a batsman trying to save the match by remaining not out 1n a last wicket partnership when a run chase is no longer viable. Strike Rate has an additional problem, in that if a player fails to take a wicket, a value for SR is not returned as the divisor is zero.

Thus SR is not suitable for evaluation on an innings by innings basis. This measurn could be calculated using all the match results for a season, but in terms of selection and monitoring a player's performance, it is too late to address an individual's worth at the end of the season. Thus only players who have taken wickets can have strike rate as a performance measure.

Bracewell (1998) detailed a novel way to evaluate individual bowling performance, incorporating SR and ER into two separate indices that considered relative performance to the team. This involved an attempt to form ratio's that took into account an individual 's performance in relation to the team performance. The Attack Ratio involved inverting SR for both team and individual so that wickets taken was no longer the denominator.

However it was found that as the number of overs bowled by an individual increased, the score for both indices tended to zero. This was because as a player bowls more and more overs (approaches 50%) this player is having a huge influence on the team performance. His performance therefore reflects the team performance very closely.

The final evolution of performance measures for bowlers involved multiplying the ratio's by a weighting factor related to time (overs). The problem described earlier was removed in this way.

In addition it was found the Attack index needed to be multiplied by a wicket weighting factor, defined in terms of w, the number of wickets taken in any innings. This index is therefore innings specific whereas the other measures are more general .

**Investigation of Bowling Measures**

Of the statistical analyses performed using cricket data, bowling is an area deficient in research. Only Kimber (1993) and Bracewell (1998) have examined how to measure an individual's bowling performance. Kimber sought to do this via a graphical display based on Strike Rate and Economy Rate, whereas Bracewell tried extending these values relative to the team.

**Randomness**

Very little research has been done on the aspect of randomness in an individual's performance in cricket. A distantly related team sport, baseball, was found to be essentially random (Cook 1977). There is anecdotal evidence supporting the claim that the role of an individual within a game is random, generally commenting on the apparent lack of predictability of cricket. Berkmann, (1990), Brittenden (1994) and Turner (1998) are just a small selection of cricket observers that subscribe to the unpredictability of cricket view Hunting through player biographies also reveals that those who play the game express this view

Danaher ( 1989) applied a Run's test to 6 English County Cricketers and found that none showed a significant runs pattern at the 5% significance level. The batsmen chosen were of varying batting ability but chosen because they were either top, or close to the top, of their team's batting averages list.

Kumar ( 1996) suggested that cricket is not by chance. However, this assertion was based solely upon over run rates in one-day cricket. The implications of this are manifested in the troublesome interrupted match rules. If over rates were random, then the simple Average Run Rate (ARR) rule would suffice, as this is based on the assumption that run rate of the batting side does not change during the innings. Instead, the resources available to a team play an important role in determining the outcome of a one-day match. One only needs to look to the Duckwort~ Lewis model (1996) to see the effect that time (overs in hand) and wickets in hand have in determining a batting side's capacity for team total. Team strategies also illustrate this point. As a simple illustration of batting capacity, this model accepts the fact that a side is more capable (or daring) of scoring runs when only 2 wickets have been lost, as opposed to being 8 down, with 10 overs remaining. The reasoning behind this is; with the loss of only 2 wickets, presumably the better batsmen are still available, and there are plenty of individual's remaining. Thus batsmen are more able to go after their shots, as the consequences to the team of their dismissal are not as great.

Whereas, a batting side with 8 wickets down needs to adopt a more cautious approach , as once a team is dismissed, there is no further chance of adding to the team total.

**Distribution of Performance Measure**

Pollard (1977) conceded "that a more elaborate model needs to be developed to describe the distribution of batsman's scores " This was due to the fact that previous results did not cater for the higher than expected frequencies of failures to score, compared to the theoretical models.

Bracewell (2)(1998) suggested a discrete version of a mixed exponential distribution for score and a relatively new concept in cricket statistics, contribution, based upon 5609 observations of individuals in the top 6 of the batting order from New Zealand domestic first class cricket. This involved separating the occurrence of zero and recalculating

the mean to find the parameters of the distribution involving the non-zero values.

Economy Index As indicated in 2.1 0 Bracewell 's (2)(1998) economy index is:

ECONOMY INDEX= [ECONOMY RATIO x /OVERS]

Where Economy Ratio has been defined previously and overs is the number of overs bowled by the individual in the innings.

Standardising the above equation by first subtracting the mean (0.3657) and then dividing by the standard deviation (3.2016) gives a value to comparable to the standardised attack index. A 95% Confidence interval for the mean reveals that the population mean probably lies between 0.3851 and 0.3463. As zero is not contained within this confidence interval the value for the mean can not be ignored and must be included in the standardisation.

Similarly a 95% confidence interval for the population standard deviation shows that it probably falls between 3.2001 and 3.2035. Due to 1 not falling in this interval, the value given for standard deviation needs to be used to standardise the economy index.

If the probability distribution of a population from which the sample is gathered is known , then the probability distribution of the various statistics computed from the sample data can be determined (Montgomery, 1997). More importantly, it can be established what a player is expected to score and thus their progress can be monitored, which is especially relevant for team selection.

A population is a set of measurements that can be described by a set of numerical measures called parameters (Ott, Mendenhall , 1985). In most applications of statistics the parameters are not known but inferences about them are made using information contained in a sample.

For time series analysis it is assumed that for each time point t, Z1 is a random variable. Thus the behaviour of Zt will be determined by a probability distribution (Cryer). In this instance time t, refers to each innings and Z1 refers to a performance output.

Previous studies have assumed that the data are independent, in that for each individual bowler the previous match result does not have a direct impact on the following match result. At first class level this is a safe assumption as it is presumed that players who reach this level have developed the necessary mental skills.

According to the analyses performed individual batting scores are best modelled by a mixed geometric distribution, mixed in two parts, the zero portion and non-zero portion. Batting contribution is best modelled by the negative binomial distribution (with r set equal to 1 ). The zero component of this distribution represents the zero portion of the score distribution.

It is important to note that the negative binomial distribution and the parameter from the contribution distribution, model the occurrence of zero amongst individual scores. This is an interesting phenomenon.

Obviously either score or contribution has to be mixed as both share the same number of zeros; unless the team continually scores exactly 100 in each innings, in which case the two distributions will be equivalent. That is the score is effectively the percentage contribution, as score is continually divided by 100 runs (the team total). Considering the case of scoring 0, the probability of this occurring is the same for both contribution and score. This is because for contribution O/y = 0, where y is the team score. Due to the sample mean representing the shape parameter, there is a difference between the shapes for the score and contribution distributions.

Normality Test Bracewell (3) (1998) hypothesized the bowling indices for individuals are normally distributed. To test this hypothesis a normality test needs to be performed. The normality test for the bowling indices involved the generation of a normal probability plot. The probability for the x-values (index) is calculated then plotted against a standard normal probability score. A least-squares line is fitted to the points. This forms an estimate for the cumulative distribution function from which the data for the population is drawn. The Anderson-Darling test for normality is used, which is an ECDF (empirical cumulative distribution function) based test.

Obviously either score or contribution has to be mixed as both share the same number of zeros; unless the team continually scores exactly 100 in each innings, in which case the two distributions will be equivalent. That is the score is effectively the percentage contribution, as score is continually divided by 100 runs (the team total). Considering the case of scoring 0, the probability of this occurring is the same for both contribution and score. This is because for contribution O/y = 0, where y is the team score. Due to the sample mean representing the shape parameter, there is a difference between the shapes for the score and contribution distributions.

Of the individual disciplines, bowling is perhaps the hardest to evaluate quantitatively. A typical bowling analysis consists of four variables, Runs conceded. Maidens bowled, Overs bowled and Wickets taken. There is no easy way of interpreting these values independently. History plays a large part of how these statistics are perceived as does the game situation. This section briefly reviews the statistical methods for evaluating an individual's bowling performance.

Kimber (1993) proposed a two-dimensional graphical display for comparing bowlers in cricket based on strike rate (SR) and economy rate (ER), taking advantage of the relationship that these two values have with the Bowling Average (AV).

SrxER=100AV

These values are traditionally calculated as follows the Economy Rate (ER) is defined as the runs conceded per ball.

$$\text{Economy rate} = \frac{\text{Total runs conceded}}{\text{Total balls faced}}$$

However, this relationship does not take into consideration the team situation, and other confounding variables that confront a bowler, such as the state of the game, combined with environmental factors, as these can have an impact on how the specific individual's involved, batsman and bowler, approach each delivery. As a brief example, a batsman 1s more likely to attack the bowler towards the end of the innings, with wickets remaining in a

run chase, than a batsman trying to save the match by remaining not out 1n a last wicket partnership when a run chase is no longer viable. Strike Rate has an additional problem, in that if a player fails to take a wicket, a value for SR is not returned as the divisor is zero

Thus SR is not suitable for evaluation on an innings by innings basis. This measurn could be calculated using all the match results for a season, but in terms of selection and monitoring a player's performance, it is too late to address an individual's worth at the end of the season. Thus only players who have taken wickets can have strike rate as a performance measure.

Bracewell (1998) detailed a novel way to evaluate individual bowling performance, incorporating SR and ER into two separate indices that considered relative performance to the team. This involved an attempt to form ratio's that took into account an individual 's performance in relation to the team performance. The Attack Ratio involved inverting SR for both team and individual so that wickets taken was no longer the denominator. The ratios are defined as follows

Economy Ratio= (Opposition Total I Total Overs - Runs Conceded I Overs] Attack Ratio = [Wickets/Overs - Total wickets/Total Over's]

**DISTRIBUTION FITTING**

However it was found that as the number of overs bowled by an individual increased, the score for both indices tended to zero. This was because as a player bowls more and more overs (approaches 50%) this player is having a huge influence on the team performance. His performance therefore reflects the team performance very closely.

The final evolution of performance measures for bowlers involved multiplying the ratio's by a weighting factor related to time (overs). The problem described earlier was removed in this way

In addition it was found the Attack index needed to be multiplied by a wicket weighting factor, defined in terms of w, the number of wickets taken in any innings. This index is therefore innings specific whereas the other measures are more general .

The wicket weighting factor in the Attack Index is given by p(w), the probability of taking a certain number of wickets in an innings. Standardisation allows the indices to be compared on similar scales.

**MEASURES OF CENTRAL TENDENCY AND DISPERSION**

These are the fundamental building blocks for understanding any dataset.

**Mean (μ or $\bar{x}$):**

**Detail:** The most common average. You sum all the values in a dataset and divide by the number of values.

**Application in Cricket:**

**Batting Average:** As discussed, this is the mean runs scored per dismissal.

- **Mean Bowling Speed:** Average speed of a bowler's deliveries.
- **Average Catches per Match:** For a fielder.

○ **Why it matters:** Gives a quick snapshot of "typical" performance. However, it can be heavily influenced by outliers (e.g., a single very high score by a batsman can inflate their average if they haven't played many innings).

- **Median:**
  - **Detail:** The middle value when data is ordered. If there's an even number of values, it's the average of the two middle values.
    - **Application in Cricket:**
    - **Median Score:** If a batsman has scores of 10, 20, 50, 70, 100, the median is 50. If their scores were 0, 0, 5, 100, 150, the mean might be high but the median reveals a different story about consistency.
  - **Why it matters:** It's robust to outliers. For highly skewed performance data (e.g., a bowler who takes many cheap wickets but sometimes gets hit for many runs), the median economy rate might give a more stable picture of typical performance than the mean.
- **Mode:**
  - **Detail:** The most frequently occurring value.
    - **Application in Cricket:**
    - **Most Frequent Dismissal Type:** For a batsman (e.g., "caught" might be their mode of dismissal).
    - **Most Common Score Interval:** What score range does a batsman most often fall into (e.g., 20-30 runs).
  - **Why it matters:** Useful for identifying common patterns or habits.
- **Standard Deviation (σ or s):**
  - **Detail:** It quantifies the amount of variation or dispersion of a set of data values around the mean. A low standard deviation indicates that the data points tend to be close to the mean, while a high standard deviation indicates that the data points are spread out over a wider range of values.
  - **Formula Intuition:** It's the square root of the average of the squared differences from the mean. Squaring the differences makes sure positive and negative deviations don't cancel out, and gives more weight to larger deviations. The square root brings it back to the original units.
  - **Application in Cricket:**

    **Batting Consistency:** A batsman with an average of 40 and a standard deviation of 5 is very consistent. Another batsman with an average of 40 and a standard deviation of 20 is inconsistent (scores range widely).

    **Bowling Line & Length:** A bowler with a low standard deviation in their delivery's landing spot is highly accurate.
  - **Speed Variation:** For a fast bowler, the standard deviation of their speed can indicate how much they vary their pace.
  - **Why it matters:** Provides crucial insight into a player's reliability and predictability. A player with a high mean but also high standard deviation might be a "match-winner" on their day, but also prone to failures.
- **Coefficient of Variation (CV):**

○ **Detail:** It expresses the standard deviation as a percentage of the mean. This is unitless, making it ideal for comparing consistency across different metrics or players.

- **Formula:**

CV=(Standard Deviation/Mean)×100%

- **Application in Cricket:**
  - **Comparing Consistency:** Is a batsman with an average of 50 and σ=10 more consistent than a bowler with an economy of 4.0 and σ=0.5? You can compare their CVs. The batsman's CV = (10/50)*100 = 20%. The bowler's CV = (0.5/4.0)*100 = 12.5%. The bowler is relatively more consistent in their economy.
- **Why it matters:** Allows for fair comparisons of variability when the means are very different, or when the units are different.

**PROBABILITY AND DISTRIBUTIONS**

Understanding the likelihood of events is fundamental to strategy.

- **Probability (P(E)):**
  - **Detail:** A numerical measure of the likelihood that an event will occur, ranging from 0 (impossible) to 1 (certain).
  - **Application in Cricket:**
    - P (wicket on next ball): Based on bowler form, pitch, batsman.
    - P(boundary on next ball): Based on batsman form, field setting.
    - P (win | score X runs): The probability of winning a match given a certain score.
  - **Why it matters:** Informs risk assessment, decision-making (e.g., whether to go for a risky shot or play safe), and strategic planning.
- **Probability Distributions:**
- **Normal Distribution:**
- **Detail:** The classic "bell curve." Many natural phenomena follow this distribution (e.g., heights, IQ scores). Characterized by its mean and standard deviation. Data points are symmetrically distributed around the mean.
- **Application in Cricket:**
- **Bowling Speed:** While individual balls might vary, a bowler's average speed over many deliveries often approximates a normal distribution.
- **Run Rate Distribution:** The distribution of run rates per over across a long period might show a normal distribution around the average.
- **Why it matters:** If data is normally distributed, we can make strong inferences. For example, roughly 68% of data falls within one standard deviation of the mean, 95% within two, and 99.7% within three. This helps predict ranges of performance.
  - **Poisson Distribution:**
- **Detail:** Describes the number of events occurring in a fixed interval of time or space, given a known average rate of occurrence and that these events occur independently.
- **Application in Cricket:**
- **Number of Wickets in an Innings:** Given a team's average wicket-taking rate, you can model the probability of taking 0, 1, 2, etc., wickets in a particular spell or innings.
- **Number of Boundaries in an Over:** Predicting the likelihood of hitting a certain number of fours or sixes in an over.
- **Why it matters:** Useful for modeling discrete event counts, especially for rare events or events occurring at a constant average rate.
  - **Binomial Distribution:**
    - **Detail:** Models the number of "successes" in a fixed number of independent "trials," where each trial has only two possible outcomes (success/failure) and the probability of success is constant.
    - **Application in Cricket:**
    - **Catches Taken:** Out of 5 catching opportunities, what's the probability a fielder takes 3 catches (given their historical success rate)?
    - **Dot Balls Bowled:** Out of 6 balls in an over, what's the probability a bowler bowls 4 dot balls?
    - **Why it matters:** Ideal for situations with a fixed number of trials and two outcomes, helping to predict success rates for specific actions.

**Inferential Statistics**

This is where we move from describing what happened to making predictions and drawing conclusions.

- **Hypothesis Testing:**
  - **Detail:** A formal procedure to decide whether to accept or reject a claim (the null hypothesis, H0) about a population based on sample data. You formulate H0 and an alternative hypothesis (H1). You then collect data and calculate a test statistic, which gives you a p-value.
  - **p-value:** The probability of observing data as extreme as (or more extreme than) what you got, *assuming the null hypothesis is true*.
    - If $p<\alpha$ (a pre-determined significance level, usually 0.05), you reject H0. This suggests the observed effect is statistically significant and likely not due to random chance.
    - If $p\geq\alpha$, you fail to reject H0. This means there isn't enough evidence to conclude a significant effect.
  - **Application in Cricket:**
    - **Comparing Performance:** Is Player A's average truly higher than Player B's, or is the difference just due to random variation? (H0: A's average = B's average; H1: A's average □= B's average).
    - **Impact of a New Batting Technique:** Does a new technique significantly improve a batsman's strike rate? (H0: Strike rate unchanged; H1: Strike rate increased).
    - **Pitch Effect:** Does playing on a particular pitch type significantly reduce a bowler's economy?
  - **Why it matters:** Provides a rigorous framework for making data-driven decisions and avoiding false conclusions based on small sample sizes or random fluctuations.
- **Correlation Coefficient (r):**
  - **Detail:** A numerical value between -1 and +1 that indicates the strength and direction of a *linear* relationship between two quantitative variables.
    - r=1: Perfect positive linear relationship (as one increases, the other increases proportionally).
    - r=−1: Perfect negative linear relationship (as one increases, the other decreases proportionally).

- r=0: No linear relationship.

○ **Application in Cricket:**

- **Runs and Balls Faced:** Strong positive correlation for batsmen.
- **Bowling Speed and Wickets:** Is there a correlation between higher bowling speeds and more wickets? (Not always a perfect linear relationship, but interesting to explore).
- **Dot Ball % and Economy Rate (bowlers):** Strong negative correlation (more dot balls usually means better economy).

○ **Why it matters:** Helps identify potential relationships between different performance metrics, which can inform coaching decisions or strategic insights. *Important note: Correlation does not imply causation!*

- **Regression Analysis (especially Linear Regression):**

○ **Detail:** A powerful statistical method used to model the relationship between a dependent variable (what you want to predict) and one or more independent variables (predictors). Linear regression models this relationship with a straight line.

○ **Equation (Simple Linear Regression):** $Y=\beta0+\beta1X+\epsilon$

- Y: Dependent variable (e.g., Runs Scored)
- X: Independent variable (e.g., Balls Faced)
- β0: Y-intercept (the value of Y when X is 0)
- β1: Slope (the change in Y for a one-unit change in X)
- ϵ: Error term (the unpredictable part)

○ **Application in Cricket:**

- **Predicting Runs:** Predict a batsman's runs based on the number of balls they faced, or the specific overs they played.
- **Impact of Boundary Hitting:** Model how boundary percentage impacts a team's total score.
- **Predicting Wickets:** Predicting wickets taken based on line, length, and speed metrics.

○ **Why it matters:** Enables prediction and helps understand the *magnitude* of the influence of one variable on another. It can help answer "how much" questions.

**Advanced Concepts (often incorporating Machine Learning)**

- **Optimization Algorithms:**

○ **Detail:** Mathematical procedures used to find the best possible solution from a set of alternatives, often by maximizing or minimizing some objective function subject to certain constraints.

○ **Application in Cricket:**

- **Optimal Batting Order:** Given player strengths and weaknesses against different bowling types, and match situations, what's the optimal batting order to maximize expected runs?
- **Field Placement Optimization:** Where should fielders be placed to minimize runs conceded and maximize wicket chances against a specific batsman on a specific pitch?
- **Player Workload Management:** Optimizing training schedules to maximize performance and minimize injury risk.

○ **Why it matters:** Moves beyond analysis to prescriptive solutions, helping teams make the best decisions for a given objective.

- **Time Series Analysis:**

○ **Detail:** A set of techniques for analyzing data points collected over time. It looks for trends, seasonality, cycles, and irregular components.

○ **Application in Cricket:**

- **Player Form Tracking:** Monitoring a player's batting average or economy rate over consecutive matches to identify dips or improvements in form.
- **Forecasting Performance:** Predicting a player's likely performance in upcoming matches based on their recent form and historical trends.
- **Identifying Fatigue:** Analyzing workload metrics (e.g., GPS data, bowling spells) over time to detect patterns that might indicate fatigue or injury risk.

○ **Why it matters:** Recognizes that performance isn't static and evolves over time. It helps understand dynamic changes and forecast future states.

By applying these mathematical terms and techniques, cricket analysts can move beyond simple statistics to build sophisticated models that provide deep insights into individual player performance, inform strategic decisions, and ultimately, enhance a team's chances of success.

**Conclusion**

In conclusion, cricket is more than just a sport; it's a way of life. As the "Gentleman's Game," cricket celebrates values of sportsmanship, companionship, and fair play that transcend the boundaries of the field. In this conclusion from this dessertation I have taken a keen view to different aspects of the games.this dessertation has helped me to learn the sport cricket with more seriousness and makes it more interesting

I have learned various formulas through which cricket is carried through and the whole games works.through this research I have came to known that cricket is not just a game it's a full subject to read.

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Original Research

# Impact Of Kinesio Taping Versus Strength Training in Patellofemoral Pain Syndrome in School Going Athletes

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**Abstract**

**Background:** Patellofemoral Pain Syndrome (PFPS) is one of the most prevalent causes of anterior knee pain, especially among young adults and athletes, characterized by diffuse, retro-patellar discomfort aggravated by activities like squatting, stair climbing, or prolonged sitting[1,2,3]. Both Kinesio Taping (KT) and Strength Training (ST) are widely adopted conservative approaches, but their comparative effectiveness remains under evaluation[5,8].

**Purpose:** This study aimed to compare the effectiveness of Kinesio Taping versus Strength Training in reducing pain and improving functional performance in School Going Athletes with Patellofemoral Pain Syndrome.

**Result:** Both Kinesio Taping and Strength Training significantly reduced pain and improved function, but Strength Training yielded superior long-term functional gains while Kinesio Taping provided more immediate pain relief performance in School Going Athletes with Patellofemoral Pain Syndrome.

**Keywords:** Patellofemoral Pain Syndrome, Kinesio Taping, Strength Training, Knee Pain, Rehabilitation.

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## Introduction

Patellofemoral Pain Syndrome (PFPS) is a non-traumatic musculoskeletal disorder commonly affecting adolescents, athletes, and active adults, particularly females. The condition is characterized by anterior knee pain exacerbated during activities such as stair climbing, running, or prolonged sitting [3]. Muscle imbalances, poor patellar tracking, and overuse are primary contributing factors [4].

Conservative physiotherapy approaches like Strength Training (ST) and Kinesio Taping (KT) are widely used in clinical practice. KT is believed to improve proprioception, correct patellar alignment, and enhance circulation [1,6], whereas ST focuses on strengthening the quadriceps, gluteal, and hip abductors to reduce knee joint stress [2,8,9]. Though both methods show promise, their comparative efficacy in PFPS management remains underexplored [10,14].

## Materials and Methodology

### Objective of the Study

To evaluate and compare the effectiveness of Kinesio Taping versus Strength Training in improving pain relief and functional mobility among in School Going Athletes diagnosed with Patellofemoral Pain Syndrome [3,12].

### Study Design

Randomized controlled trial (RCT).

### Sampling Method

Random sampling

### Duration of Study

8 weeks.

### Inclusion Criteria

- Age: 15–20 years.
- Diagnosed Patellofemoral Pain Syndrome (PFPS) confirmed by clinical examination.
- Pain during daily activities like stair climbing or squatting.

### Exclusion Criteria

- History of knee surgery.
- Ligamentous injury or meniscal tear.
- Neurological disorders affecting lower limbs.
- Current corticosteroid medication use.

### Tools Used in the Study

- Visual Analogue Scale (VAS) for pain.
- Kujala Anterior Knee Pain Scale for functional assessment.
- Goniometer for range of motion.

### Method

Participants (n=40) were randomly divided into two groups:

- **Group A** received Kinesio Taping (applied twice weekly) combined with a basic stretching protocol (three sessions per week).
- **Group B** performed a structured Strength Training program focusing on quadriceps, gluteus medius, and core muscles (three sessions per week).

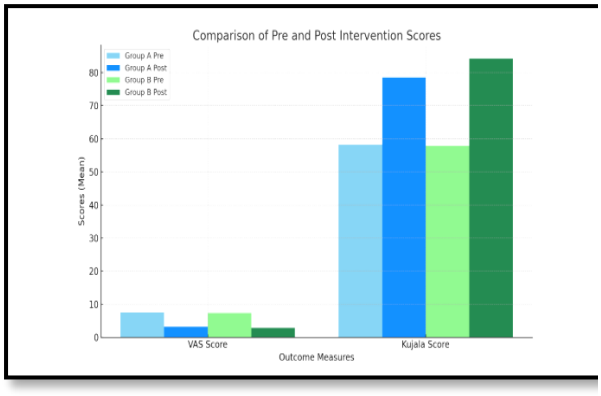
Outcome measures were recorded at **baseline, week 4, and week 8**.

## Results

- Both groups showed statistically significant improvements in pain and function ($p<0.05$).
- **Group A (Kinesio Taping)**: Immediate reduction in VAS scores within 2 weeks but plateaued by week 8.
- **Group B (Strength Training)**: Slower initial pain relief but superior functional improvement (Kujala score) by the 8th week.

## Data analysis

| Outcome Measure | Group A (KT) Pre (Mean±SD) | Group A Post (Mean±SD) | Group B (ST) Pre (Mean±SD) | Gro Pos (Me |
|---|---|---|---|---|
| VAS Score | 7.5 ± 1.2 | 3.2 ± 1.0 | 7.3 ± 1.1 | 2.8 |
| Kujala Score | 58.2 ± 5.5 | 78.5 ± 6.3 | 57.9 ± 6.0 | 84. |




**Bar Graph: Pre vs. Post Intervention**

**1. VAS Score Comparison (Lower = Better)**

| Group | Pre VAS | Post VAS |
|---|---|---|
| KT (Group A) | 7.5 | 3.2 |
| ST (Group B) | 7.3 | 2.8 |

2. **Kujala Score Comparison (Higher = Better)**

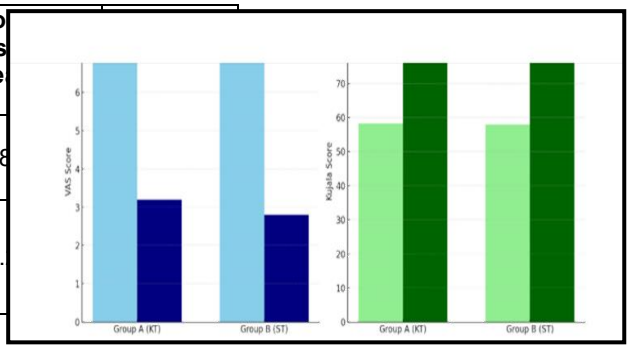
| Group | Pre Kujala | Post Kujala |
|---|---|---|
| KT (Group A) | 58.2 | 78.5 |
| ST (Group B) | 57.9 | 84.2 |

- **VAS Scores** decreased in both groups, indicating pain reduction.
- **Kujala Scores** increased, reflecting functional improvement—more significantly in the ST group

**Interpretation:**

- **VAS Score (Pain):** Both groups showed significant pain reduction, with Group B (ST) showing slightly better improvement. The difference between groups was statistically significant ($p = 0.04$).
- **Kujala Score (Function):** Functional scores improved in both groups, with Group B again showing a greater improvement post-intervention. The intergroup difference was statistically significant ($p = 0.03$).

**Bar chart showing the VAS and Kujala score changes before and after treatment in both KT and ST groups:**




## DISCUSSION

The present study evaluated and compared the effects of Kinesio Taping (KT) and Strength Training (ST) on pain reduction and functional improvement in school-going athletes diagnosed with Patellofemoral Pain Syndrome (PFPS). Both interventions resulted in statistically significant improvements in pain (VAS scores) and functional performance (Kujala scores), indicating that KT and ST are effective conservative approaches in PFPS management [1,6,7].

**Group A (KT)** demonstrated a more rapid decrease in VAS scores within the first two weeks, supporting findings by Thelen et al. (2008) and Lee & Lee (2013), who reported that KT enhances proprioception, supports patellar alignment, and offers short-term pain relief. However, this improvement plateaued by week 8, suggesting KT may not sustain long-term functional benefits when used alone [10,11].

**Group B (ST)** exhibited a slower onset of pain relief but showed superior functional improvement by the eighth week, as reflected by a greater increase in Kujala scores. These findings align with previous research (Bolgla & Boling, 2011; Barton et al., 2015; Mörtl et al., 2012), which highlighted the effectiveness of strength training—particularly targeting the quadriceps, hip abductors, and gluteal muscles—in enhancing knee joint stability and reducing biomechanical stress [2,8,9].

The statistically significant difference in functional scores ($p = 0.03$) and pain scores ($p = 0.04$) between the groups at the end of 8 weeks underscores the long-term advantage of ST over KT in functional rehabilitation. This supports the consensus that while

KT may provide an early analgesic effect, ST is more beneficial in addressing the underlying biomechanical deficits contributing to PFPS [3,14].
It is noteworthy that this study was conducted in a school-going athletic population (ages 15–20), a group particularly vulnerable to PFPS due to growth-related musculoskeletal imbalances and high physical demands. The outcomes highlight the importance of tailored rehabilitation strategies in young athletes, emphasizing long-term joint stability and performance restoration

## Conclusion

This randomized controlled trial demonstrates that both Kinesio Taping and Strength Training are effective in managing Patellofemoral Pain Syndrome among school-going athletes. However, their outcomes differ in time course and magnitude. Kinesio Taping offers faster initial pain relief but lacks sustained functional benefits. In contrast, Strength Training leads to gradual but superior long-term improvement in knee function and pain reduction.
Thus, for clinicians treating young athletes with PFPS, incorporating structured strength training should be considered a cornerstone of rehabilitation. Kinesio Taping may be used as an adjunct in the initial phase to manage acute symptoms and facilitate engagement in exercise-based therapy. [3,8,14]

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Review Article

# Understanding How Ciprofloxacin Affects Bacteria

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**Abstract**
Ciprofloxacin is an antibiotic that kills bacteria quickly, but exactly how it works is still unclear. In this study, researchers looked at how ciprofloxacin affects *Escherichia coli* using both traditional lab methods and advanced flow cytometry. They treated growing bacterial cells with different concentrations of ciprofloxacin (from 0.1 to 100 times the minimum inhibitory concentration or MIC) and examined them over time. Although high doses of ciprofloxacin significantly reduced the number of bacteria that could grow on plates, most of the cells remained intact and active under the microscope. These bacteria still had functioning membranes, showed normal metabolism, and even continued making proteins up to 5 hours after treatment. This means that many of the bacteria were alive and functioning, even though they couldn't grow in normal culture conditions. The findings suggest that ciprofloxacin-exposed *E. coli* cells can enter a "viable but nonculturable" (VBNC) state—a survival mode where they stay alive but don't divide or form colonies.

**Keywords:** *E. coli,* Ciprofloxacin, Minimum inhibitory concentration (MIC)

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## Introduction

Ciprofloxacin is a broad-spectrum antibiotic belonging to the quinolone class, known for its potent bactericidal activity against a wide range of Gram-negative and Gram-positive bacteria[(1)]. It functions mainly by inhibiting bacterial DNA gyrase and topoisomerase IV, enzymes essential for DNA replication and transcription [(12,14,32)]. While ciprofloxacin is considered rapidly bactericidal, the exact sequence of cellular events that leads to bacterial death is still not completely understood [(29)]. Previous studies have proposed that ciprofloxacin may induce structural damage to bacterial cell membranes, leading to leakage of cytoplasmic content and death[(4,7)]. However, other evidence indicates that many bacteria exposed to the drug remain metabolically active, even though they are unable to form colonies[(9)]. This observation challenges the traditional reliance on colony-forming unit (CFU) counts to assess bacterial viability.

In this context, the present study by Mason *et al*. (1995)[(18)] aimed to investigate the effects of ciprofloxacin on *Escherichia coli* using both conventional and modern methods. These included light microscopy and advanced flow cytometry, allowing for a detailed assessment of bacterial membrane potential, membrane integrity, metabolic activity, and cell morphology. This multifaceted approach helps to clarify whether bacteria truly die or enter a metabolically active but non-growing state following exposure to ciprofloxacin [(31)].

The primary goal of this study was to investigate how ciprofloxacin affects *Escherichia coli* cells at both physical and metabolic levels. Specifically, the researchers aimed to determine whether bacteria that lose the ability to form colonies after antibiotic exposure are still viable in terms of membrane integrity, energy production, and protein synthesis. Another important objective was to understand how bacterial morphology and respiration are influenced by different concentrations of ciprofloxacin [(13)]. By using flow cytometry with specific fluorescent dyes, the study sought to measure membrane potential, cell permeability, and metabolic activity in real time [(5)]. Additionally, the researchers aimed to examine stress responses such as SOS induction by tracking protein synthesis through enzymatic assays. These combined goals helped evaluate whether ciprofloxacin merely stops bacterial growth or also causes immediate and irreversible cellular death.

## 2.Materials and Methods

**2.1.Bacterial Strains and Culture Conditions:** Two *Escherichia coli* strains were used: KL16 and PQ37 (harboring *sulA::lacZ* SOS fusion). Cultures were grown at 37 °C in Iso-Sensitest or Brain Heart Infusion (BHI) broth (filtered through 0.2 µm filters for flow cytometry) with shaking at 200 rpm.

**2.2.Antibiotic Preparation and MIC Determination:**

Ciprofloxacin (gifted by Bayer, UK) was dissolved in 0.01 N NaOH and diluted in sterile deionized water. The minimum inhibitory concentration (MIC) was

determined using broth dilution in Iso-Sensitest broth, with a starting inoculum of $10^5$ CFU/ml. MICs were 0.06 µg/ml for KL16 and 0.03 µg/ml for PQ37. Ciprofloxacin, a fluoroquinolone antibiotic, was generously provided by Bayer, United Kingdom. For experimental use, the compound was first dissolved in 0.01 N sodium hydroxide (NaOH) to ensure complete solubilization. This stock solution was then further diluted with sterile deionized water to achieve the desired working concentrations suitable for microbiological assays [22,16].

To assess the antibiotic susceptibility of the two *E. coli* strains used in the study (KL16 and PQ37), the minimum inhibitory concentration (MIC) of ciprofloxacin was determined using the standard broth dilution method. Iso-Sensitest broth served as the growth medium for the assay. An overnight culture of each strain was diluted to a final inoculum of approximately $10^5$ colony-forming units per milliliter (CFU/ml) in each test well or tube.

The cultures were then incubated at 37 °C for 18 hours. Following incubation, the MIC was defined as the lowest concentration of ciprofloxacin that completely inhibited visible bacterial growth. The determined MIC values were:

- 0.06 µg/ml for *E. coli* KL16
- 0.03 µg/ml for *E. coli* PQ37

These MIC values were used as a reference to prepare ciprofloxacin treatments at various multiples of the MIC (e.g., 0.1×, 1×, 10×, 100×) for further experiments assessing bacterial viability, morphology, membrane integrity, and metabolic activity.

**2.3.Experimental Setup:**

Early-log phase cultures ($10^7$ CFU/ml) of KL16 were divided into five groups: control and ciprofloxacin-treated (0.1×, 1×, 10×, and 100× MIC). Cultures were incubated for 120 min, and samples (1 ml) were collected at 0, 15, 30, 60, 90, and 120 min. Samples were centrifuged, washed, and resuspended in fresh broth. Aliquots were stained with DiBAC4(3), propidium iodide (PI), or CTC for flow cytometry; the rest was used for viable plate counts.To investigate the effects of ciprofloxacin on *Escherichia coli* KL16, cultures were first grown to the **e**arly logarithmic phase, reaching a concentration of approximately $10^7$ colony-forming units per milliliter (CFU/ml). This growth phase was chosen because bacteria are metabolically active and highly responsive to antibiotics during exponential growth.

The culture was then divided into five equal parts, each containing 25 ml of bacterial suspension: One group served as the untreated control, which was not exposed to ciprofloxacin. Four groups were treated with ciprofloxacin at concentrations corresponding to 0.1×, 1×, 10×, and 100× the minimum inhibitory concentration (MIC), based on the previously determined MIC for KL16.

All control and ciprofloxacin-treated *E. coli* KL16 cultures were incubated at 37 °C with shaking for a total duration of 120 minutes. To assess the bacterial response over time, 1 ml samples were aseptically collected at six time points: 0 minutes (prior to antibiotic exposure), and at 15, 30, 60, 90, and 120 minutes post-exposure. Each collected sample was processed systematically. First, samples were centrifuged at 13,000 rpm for 1 minute using an Eppendorf microcentrifuge to pellet the bacterial cells. The pellets were then washed once with fresh Iso-Sensitest broth to eliminate any residual antibiotic and resuspended in the same medium to ensure consistency across samples.

To evaluate various physiological parameters, aliquots of the resuspended sample were stained with specific dyes for flow cytometry. DiBAC4(3) was used to assess membrane potential, as depolarized cells take up this dye. Propidium iodide (PI), a nucleic acid-binding dye, was employed to evaluate membrane integrity, since it penetrates only cells with compromised membranes. CTC (cyanoditolyltetrazolium chloride), a redox-sensitive dye, was used to detect metabolic activity by identifying actively respiring cells. Each of these dyes was added to separate 0.2 ml aliquots of the sample, which were then subjected to flow cytometric analysis to measure single-cell physiological responses.

The remaining portion of each sample was utilized for viable plate counts by plating on nutrient agar to determine colony-forming units (CFUs), providing an independent assessment of bacterial viability. This multi-parameter experimental approach enabled simultaneous analysis of bacterial viability (through CFU enumeration), membrane integrity and potential (via PI and DiBAC4(3) staining), and metabolic activity (via CTC reduction) across various ciprofloxacin concentrations and time intervals.

**2.4.Protein Synthesis Assay:**

PQ37 cultures treated with ciprofloxacin (10× MIC) were sampled every 60 min for 300 min. β-galactosidase activity was measured using the Quillardet and Hofnung method and calculated using Miller's formula.[25]

To assess protein synthesis activity in response to ciprofloxacin exposure, *Escherichia coli* PQ37, a reporter strain containing the SOS gene fusion (*sulA::lacZ*), was used. Cultures were grown to early log phase and then treated with ciprofloxacin at a concentration equivalent to 10 times the minimum inhibitory concentration (MIC). Following antibiotic treatment, samples of 0.3 ml were aseptically collected at 60-minute intervals over a period of 300 minutes (i.e., at 60, 120, 180, 240, and 300 minutes post-treatment). The β-galactosidase activity, indicative of *sulA* expression and hence the induction of the SOS response, was measured using the colorimetric method described by Quillardet and Hofnung. This assay involves the enzymatic hydrolysis of the substrate o-nitrophenyl-β-D-galactopyranoside (ONPG), which produces a yellow-colored product, o-nitrophenol, that can be quantified spectrophotometrically. The absorbance was measured at 420 nm ($A_{420}$) to detect the reaction product, and at 550 nm ($A_{550}$) to correct for cell debris and turbidity. The initial cell density was monitored at 600 nm ($A_{600}$).

The β-galactosidase activity was then calculated using Miller's standard formula: **Units = 1,000 × [$A_{420}$ – (1.75 × $A_{550}$)] / (t × v × $A_{600}$)**, where *t* is the reaction time in minutes, *v* is the volume of culture used in milliliters, and $A_{600}$ is the optical density of the culture before the assay. This

method provided a quantitative measure of protein synthesis activity over time in response to high-dose ciprofloxacin treatment. All experiments were performed in triplicate to ensure reproducibility, and representative data are reported.

**2.5. Viable Counts and Microscopy:**

CFU counts were performed using the Miles method on nutrient agar. For microscopy, bacterial numbers were counted using a Neubauer chamber under a Nikon Diaphot microscope. Cell lengths were estimated by image analysis using a calibrated string measurement method on ≥25 cells per group.[19]

To independently assess bacterial viability following ciprofloxacin treatment, colony-forming unit (CFU) counts were performed using a modified version of the Miles and Misra method. Aliquots of appropriately diluted bacterial cultures were plated onto nutrient agar and incubated to allow for colony development. The number of colonies was then counted and used to calculate the CFU per milliliter, providing a reliable estimate of viable bacterial cells capable of growth and division.

In parallel, light microscopy was employed to directly observe and quantify bacterial cells and assess morphological changes. For this, bacterial samples were loaded into a Neubauer counting chamber and examined under a Nikon Diaphot inverted microscope equipped with a camera. Bacterial cell numbers were counted in five different microscopic fields using a 40× objective under bright-field illumination to determine the average bacterial concentration per milliliter.

Additionally, bacterial cell length was measured as an indicator of morphological changes in response to ciprofloxacin. To achieve this, microscope images were transferred to a monitor via a JVC TK870E video camera. A calibrated string method was employed, where a piece of string was laid along the longitudinal axis of each bacterium to measure its length. This string length was then converted into micrometers using a known scale. The mean cell length and standard deviation were calculated from measurements of at least 25 individual cells per treatment group at the 120-minute time point, allowing for quantitative analysis of antibiotic-induced cell elongation and filamentation.

**Reproducibility:**

All experiments were performed in triplicate; representative results are presented.

**3.Results**

**3.1.Viable Counts:**

Exposure of *E. coli* KL16 to ciprofloxacin at 10× and 100× the MIC resulted in a rapid and significant decline in bacterial viability. Within the first 30 minutes, the CFU count decreased by approximately 2 log units, indicating substantial bacterial killing [6,9]. By 120 minutes, the reduction had reached 3 log units. In contrast, cultures exposed to the MIC of ciprofloxacin showed no significant change in viable counts over the same period. The control culture and the culture treated with 0.1× MIC exhibited an increase in CFU, reflecting normal bacterial growth in the absence of lethal antibiotic stress [14,22]

**3.2. Fluorescence Shifts in Fixed Cells:**

Flow cytometric analysis of ethanol-fixed *E. coli* KL16 cells stained with DiBAC4(3), propidium iodide (PI), and CTC revealed distinct changes in fluorescence intensity. Fixation, which disrupts membrane integrity and halts respiration, led to a marked increase—by at least 1 log unit—in fluorescence associated with DiBAC4(3) and PI, indicating loss of membrane potential and integrity, respectively [14,26]. Conversely, the fluorescence intensity of CTC-stained cells decreased by approximately 1 log unit, reflecting a loss of respiratory activity. These shifts confirm that the dyes effectively report on physiological status: increased DiBAC4(3) and PI fluorescence correlates with membrane damage and depolarization, while decreased CTC fluorescence indicates metabolic inactivity [11,17]

**Table.1 showing viable counts over 120 min**

**A. Viable Counts (CFU Changes over 120 min)**

| Ciprofloxacin Concentration | CFU Change at 30 min | CFU Change at 120 min |
|---|---|---|
| Control (0× MIC) | Increase | Further increase |
| 0.1× MIC | Increase | Further increase |
| 1× MIC | No significant change | No significant change |
| 10× MIC | ↓ 2 log units | ↓ 3 log units |
| 100× MIC | ↓ 2 log units | ↓ 3 log units |

**Table.2 showing viable Fluorescence Shifts in Ethanol-Fixed Cells**

**B. Fluorescence Shifts in Ethanol-Fixed Cells**

| Fluorescent Dye | Cellular Target | Change in Fluorescence (Fixed Cells) |
|---|---|---|
| DiBAC4(3) | Membrane potential | ↑ 1 log unit |
| Propidium iodide (PI) | Membrane integrity | ↑ 1 log unit |
| CTC | Respiratory (metabolic) activity | ↓ 1 log unit |
| Fluorescent Dye | Cellular Target | Change in Fluorescence (Fixed Cells) |
| DiBAC4(3) | Membrane potential | ↑ 1 log unit |

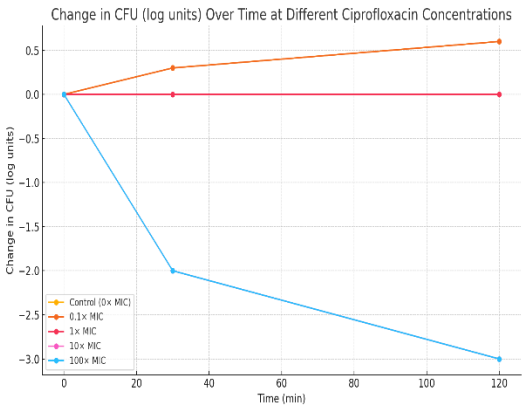


**Fig. 2 Figure: Change in CFU (log units) of *E. coli* KL16 over time in response to ciprofloxacin at varying concentrations.**

**3.3. Shifts in Bacterial Fluorescence Following Ciprofloxacin Exposure**

To evaluate the physiological changes induced by ciprofloxacin, the membrane potential, membrane integrity, and respiratory activity of *E. coli* KL16 were assessed using fluorescent dyes and flow cytometry.

**(i) Membrane Potential ($DiBAC_4(3)$ Staining):**

The membrane potential was analyzed by staining cells with $DiBAC_4(3)$, a dye that accumulates in depolarized cells. Exposure to 0.1× and 10× MIC of ciprofloxacin did not significantly alter membrane potential, with only 5–12% of cells showing fluorescence—comparable to untreated control samples [1,7]. At 1× MIC, fluorescence also remained low (5–12%) up to 90 minutes, but a slight, non-significant increase to 20% was observed at 120 minutes. However, at 100× MIC, more than 95% of the cells were $DiBAC_4(3)$-positive, indicating substantial membrane depolarization at this high concentration [5].

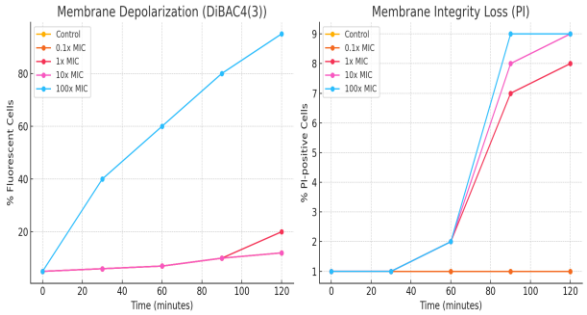


**Figure:** Effects of ciprofloxacin on membrane depolarization and integrity in *E. coli* KL16. Left: Membrane depolarization was assessed using DiBAC4(3) staining over 120 minutes. A dose-dependent increase in fluorescent cells was observed, with the highest depolarization at 100× MIC.

Right: Membrane integrity loss, measured by propidium iodide (PI) uptake, showed a sharp increase after 60 minutes at 10× and 100× MIC, indicating membrane damage. No significant PI uptake was seen in control, 0.1×, or 1× MIC groups. These results suggest that ciprofloxacin induces early membrane depolarization followed by membrane integrity loss at high concentrations.

**Table 3. Membrane Depolarization - DiBAC4(3) (% Fluorescent Cells)**

| Time (min) | Control | 0.1× MIC | 1× MIC | 10× MIC | 100× MIC |
|---|---|---|---|---|---|
| 0 | 5 | 5 | 5 | 5 | 5 |
| 30 | 6 | 6 | 6 | 6 | 40 |
| 60 | 7 | 7 | 7 | 7 | 60 |
| 90 | 10 | 10 | 10 | 10 | 80 |
| 120 | 12 | 12 | 20 | 12 | 95 |

**Table.4. Membrane Integrity Loss - PI (% PI-positive Cells)**

| Time (min) | Control | 0.1× MIC | 1× MIC | 10× MIC | 100× MIC |
|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 1 | 1 |
| 30 | 1 | 1 | 1 | 1 | 1 |
| 60 | 1 | 1 | 2 | 2 | 2 |
| 90 | 1 | 1 | 7 | 8 | 9 |
| 120 | 1 | 1 | 8 | 9 | 9 |

**1. Respiratory Activity - CTC (% Active Cells at 120 min)**

**Table.5. % Respiratory Active Cells**

| Condition | % Respiratory Active Cells |
|---|---|
| Control | 67 |
| 0.1× MIC | 90 |
| 1× MIC | 90 |
| 10× MIC | 90 |
| 100× MIC | 57 |
| Control | 67 |
| 0.1× MIC | 90 |
| 1× MIC | 90 |

**(ii) Membrane Integrity (Propidium Iodide Staining):**

Membrane integrity was measured using propidium iodide (PI), which penetrates cells with compromised membranes. In both the control group and the 0.1× MIC-treated cells, PI staining remained low (0.7–1.5%) throughout the 120-minute period. Similarly, exposure to 1×, 10×, and 100× MIC resulted in minimal PI uptake (0.6–2.5%) during the first 60 minutes. However, by 90 minutes, cells treated with 1×, 10×, and 100× MIC showed an increased PI-positive population, ranging between 7–9%, suggesting a gradual loss of membrane integrity at higher concentrations and longer exposure [6,9].

**(iii) Respiratory Activity (CTC Reduction):**

The metabolic activity of the cells was assessed by the reduction of the tetrazolium dye CTC, which fluoresces in actively respiring cells. Up to 10× MIC, ciprofloxacin did not affect respiratory activity, with around 90% of cells remaining metabolically active after 120 minutes [27]. Interestingly, a decline in fluorescence was observed in both the control group (67%) and the 100× MIC group (57%) at the 120-minute mark, indicating a general reduction in respiratory activity over time, particularly at very high drug concentrations[21,28].

**3.4. Bacterial Cell Counts:**

Flow cytometry-based total bacterial counts showed that cultures treated with 0.1× MIC and the control group exhibited an increase in cell numbers over time, indicating ongoing growth. In contrast, the bacterial counts for cultures exposed to 1×, 10×, and 100× MIC remained unchanged throughout the 120-minute incubation, reflecting a growth arrest despite sustained cell presence. [10,18]

**3.5. Cell Morphology:**

Microscopic examination revealed that the average cell length remained consistent (3.2 ± 1.1 µm) in both control and 0.1× MIC-treated cultures, suggesting that sub-MIC exposure did not induce morphological changes in the bacterial population.

**3.6. SOS Induction**: Ciprofloxacin at 10× MIC triggered strong SOS induction in *E. coli* PQ37, as indicated by elevated expression of the *sulA::lacZ* gene fusion. β-Galactosidase activity, a reporter for SOS response, rose exponentially during the first 120 minutes and continued to increase linearly over the following 180 minutes. This sustained increase reflects ongoing de novo protein synthesis despite continuous antibiotic exposure, highlighting the bacteria's active physiological state under stress.

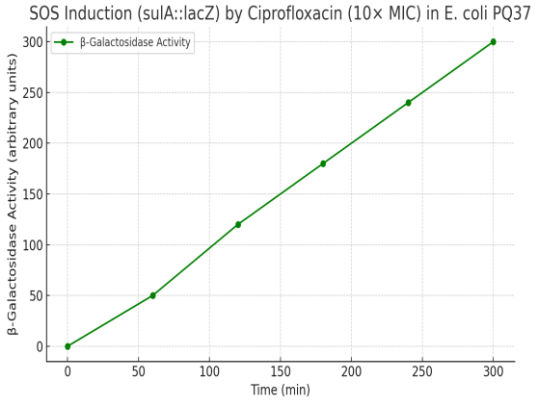


**Figure 3: SOS response induction in *E. coli* PQ37 upon ciprofloxacin exposure.**

## 4. Discussion

Ciprofloxacin, a fluoroquinolone antibiotic, is widely known for its potent bactericidal activity, primarily through inhibition of bacterial DNA gyrase and topoisomerase IV, leading to DNA damage and eventual cell death [(8)]. However, the exact sequence of physiological events that constitute ciprofloxacin-mediated killing remains complex and not fully elucidated. In this study, we combined flow cytometry, plate counts, microscopy, and reporter assays to comprehensively analyze the early cellular responses of *E. coli* to ciprofloxacin at varying concentrations.

Despite a 3-log reduction in CFU within 120 minutes at high ciprofloxacin concentrations (10× and 100× MIC), our microscopy and flow cytometry data demonstrated that most bacterial cells retained membrane integrity and metabolic activity, as indicated by exclusion of propidium iodide (PI) and reduction of CTC. Moreover, over 90% of cells maintained membrane potential at all concentrations except 100× MIC [(33)], where a significant drop was observed. These findings challenge the assumption that loss of culturability equates with cell death, aligning instead with the concept of the viable but nonculturable (VBNC) state, where cells are metabolically active yet fail to grow on sqqa WQAwaqtandard media [(21)].

The continuation of protein synthesis, as evidenced by increasing β-galactosidase activity in *E. coli* PQ37, further supports the idea of active physiological processes in ciprofloxacin-treated cells. The *sulA::lacZ* fusion, indicative of SOS response activation, showed progressive induction for up to 300 minutes [(24)]. This suggests that the bacteria are not only sensing DNA damage but also mounting a repair response, consistent with previous studies showing fluoroquinolone-induced SOS gene upregulation [(15)]. Persistent induction of SOS genes can also lead to mutagenesis, potentially contributing to antibiotic resistance development [(2)].

Interestingly, cells exposed to subinhibitory concentrations (0.1× MIC) displayed increased CFU over time, similar to untreated controls, indicating that low-level ciprofloxacin may not impair growth and could potentially prime stress response pathways. In contrast, cells exposed to 1× MIC showed static CFU counts, with no significant killing or growth, suggesting bacteriostatic effects at this threshold.

Our findings also validate the use of multi-parameter flow cytometry to distinguish between viability, membrane integrity, and metabolic function. Ethanol-fixed controls clearly demonstrated that DiBAC4(3) and PI fluorescence increased upon membrane compromise, while CTC signals decreased with metabolic arrest [(30)]. These tools enabled a nuanced understanding of bacterial fate post-antibiotic exposure beyond traditional CFU-based assays[(31)].

In conclusion, ciprofloxacin induces rapid loss of culturability in *E. coli* without immediate loss of metabolic or physical viability, highlighting a transient, stress-adapted state rather than outright cell death[(6)]. This underscores the importance of using multiple viability indicators in antimicrobial studies and suggests that the early effects of fluoroquinolones involve more than just lethal DNA damage. Moreover, persistence of protein synthesis and membrane function points to potential survival strategies that may influence treatment outcomes and resistance evolution[(10,11)].

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Review Article

# Methods for Incorporating Reinforcement Particles in Friction Stir Processing: A Review

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1

**Abstract**

Friction stir processing (FSP) is progressively recognized as a promising solid-state technique for enhancing both surface and bulk material properties by incorporating reinforcement particles into metallic matrices, thereby achieving improved mechanical, tribological, and corrosion-resistant properties. This review systematically examines the principal methods employed for particle introduction in FSP, including groove filling, drilled hole filling, pre-sintered inserts, and surface coating-assisted approaches. The influence of these techniques on particle dispersion, microstructural evolution, mechanical and tribological behaviours are critically discussed. A comparative assessment highlights the challenges associated with each method, emerging future trends and the potential integration of machine intelligence for process optimization and performance prediction..

**Keyword***:* Friction Stir Processing, Particle Reinforcement, Composite Materials, Incorporation Techniques, Process parameters.

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**Introduction:**

A microstructural modification technology called Friction Stir Processing (FSP) is derived from Friction Stir Welding (FSW) and uses severe plastic deformation and stirring action to enhance material characteristics. Both friction stir welding (FSW) and friction stir processing (FSP) are solid-state processes that produce plastic deformation and frictional heat using a rotating tool. But their aim and applications diverge most fundamentally[1]. By stirring two or more distinct materials together along a joint line, FSW is mainly used for joining them. It may produce a flawless weld without melting the base elements. FSP, on the other hand, is meant to improve the mechanical and microstructural characteristics of a specific material or restricted area rather than to join. Metal matrix composites with enhanced hardness, wear resistance, or grain refinement are frequently produced by inserting reinforcement particles into the surface or subsurface[2]. While the tools and working concepts of the two processes are similar, FSP differs in that it focuses on material modification rather than material joining.

FSP is primarily helpful for producing localized surface composites because it can smooth out grain structures, remove casting flaws, and evenly distribute reinforcing particles[3]. FSP minimises residual stresses and distortion by avoiding melting, in contrast to traditional fusion-based techniques, which produce better mechanical, tribological, and corrosion-resistant qualities. Consequently, FSP has been widely used in the defence, automotive, marine, and aerospace industries, where there is a need for high-performance materials with exceptional surface properties. Additionally, it serves as a sustainable alternative to advanced material processing and component life enhancement[4]. The various process parameters, such as rotational speed, traverse speed, tool tilt angle, plunge depth, and workpiece material, generate heat and cause the flow of plasticised material, which in turn affects the joining.

The present study discusses the impact of different particle incorporation techniques in friction stir processing (FSP), such as surface coating, groove filling, powder preplacement, and hybrid methods, on reinforcement distribution, bonding integrity, and resulting property enhancement is the main focus This study's unique consolidation and critical evaluation.

**2. Methods of Reinforcement Incorporation in FSP:**

Several methods have been developed to introduce reinforcement particles into the matrix during FSP, aiming to achieve enhanced material properties, homogeneous dispersion, and strong interfacial bonding[5].

**2.1 Groove Filling Technique**:

A widely adopted method for incorporating reinforcement particles in Friction Stir Processing (FSP) is the grooving technique. It involves three main steps: machining a groove of defined dimensions into the base material, filling it with reinforcement particles (e.g., ceramics, metallics, or nanoparticles), and subsequently sealing the groove using a pinless tool. FSP follows this with a pinned tool to ensure uniform dispersion and strong interfacial bonding of the particles within the matrix, and Figure 1 illustrates the sequential steps of this

groove-filling technique. Multiple FSP passes are often employed to minimize agglomeration and enhance mechanical and tribological performance. Kumar et al.[6] demonstrated that multi-groove FSP of Cu/SiC composites enhanced SiC dispersion, interfacial bonding, grain refinement, hardness, and wear resistance, while moderately improving strength and reducing ductility compared to single-groove and base copper. Ashokkumar et al.[7] observed that finer grains and better particle dispersion from multi-pass processing, as well as $AlO_3$-reinforced AZ61 Mg surface composites made via FSP, demonstrated increased mechanical characteristics, with a UTS of up to 630 MPa and a hardness of 300 HV at 15% reinforcement. Kundurti et al.[8] produced AA7075 surface composites reinforced with rGO and rGO + MWCNT using optimized FSP parameters. These composites demonstrated improved hardness, impact strength, thermal conductivity, tribological properties, and refined grain structure, confirming notable improvements over the base metal through microstructural modification. Using friction stir processing and T6 heat treatment, Ravi et al.[9] showed that AA6061 composites reinforced with AlCoFeNiMn high-entropy alloy particles had refined equiaxed grains, improved surface hardness (115 HV), increased tensile strength (315 MPa), and a lower wear rate ($1.04 \times 10^{-3}$ mm³/Nm), indicating strong interfacial bonding and appropriateness for automotive and aerospace applications. Balmiki et al.[10] incorporated MWCNTs of ABS and PS, improved joint strength by 39.16%, with optimal conditions at 900 rpm and 0.1 mm/s, demonstrating enhanced performance over non-reinforced joints.

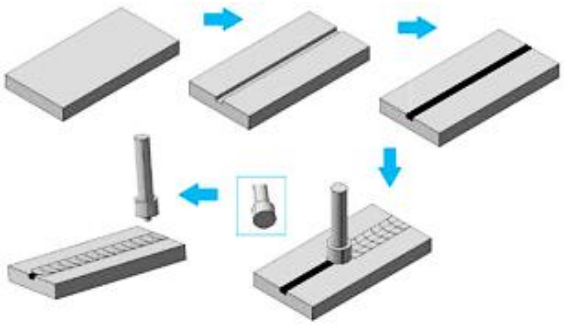

Fig.1. Grooving technique using FSP [11]

**2.2 Drilled Hole Filling Techniques**

By adding reinforcement particles to a metal matrix, the powder preplacement process in FSP produces surface composites. Using this method, a pre-machined groove or hole on the workpiece surface is filled with a defined amount of powder, such as SiC, $AlO_3$, or graphene, as shown in Figure 2. The material is then stirred with a revolving tool, producing plastic deformation and frictional heat without melting. The reinforcements' hardness, wear resistance, and corrosion resistance are improved by this method, which also allows for homogeneous dispersion and strong metallurgical bonding. As a result, it can be used in biomedical, automotive, and aerospace applications.

Abdullah et al. [12] investigated the effect of Cu nanoparticle reinforcement by FSP on AA7075, revealing that it increased corrosion resistance, mechanical properties, and grain structure. Cu nanoparticles' strengthening and protecting function was confirmed by samples C1 and C2, which showed maximum hardness (111 HV), superior corrosion resistance (Rp = 4.12 kΩ·cm²), and the greatest UTS (460 MPa), respectively. Dubey et al. [13] presented a single-stage Incremental Hole Flanging (IHF) method using a conical tool, reducing production time while enabling successful flange formation with optimized tool angles and validated deformation behavior through FEA on AA1050. Pham et al. [14] conducted a comprehensive study on the variability of Hole Expansion Ratio (HER) in DP800 steel, identifying pre-strain and pre-damage from hole punching as dominant factors. Using a surrogate model trained via neural networks and Monte Carlo simulations, they quantified HER uncertainty and provided insights for improving edge crack resistance. Chen et al.[15] systematically analyzed pin-hole occlusion failure in D25TCIF steel pistons, identifying thermo-mechanical stress concentration and oil film rupture as key causes. An optimization strategy improved oil film thickness by up to 15.36%, offering effective predictive accuracy and practical solutions for piston durability. Zhang et al. [16] developed a nonlinear FEM dynamic model for BTA deep-hole drilling, incorporating drill rod elasticity and tool–workpiece interaction. Their findings reveal guide bar wear sensitivity, chip morphology issues, and offer optimized tool geometry and feed strategies for enhanced machining quality and vibration control.

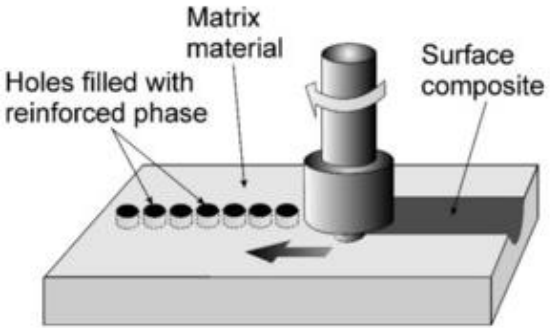


Fig.2. Reinforcement placement through the hole technique in FSP [11]

**2.3 Surface Coating Approach:**

FSP surface coating has grown into a vital tool for improving engineering materials' surface qualities without reducing their bulk properties. The requirement for this particular kind of approach develops from the limitations of traditional surface coating methods like thermal spraying, electroplating, and laser cladding, which frequently entail melting and are vulnerable to flaws like porosity, cracking, delamination, and undesired phase changes. On the other hand, FSP is a solid-state method that refines the surface microstructure and plastically deforms it by using the frictional heat produced between a rotating tool and the workpiece. By using this technique, reinforcement particles like

SiC, $AlO_3$, TiC, or graphene can be included in the surface layer, producing a uniform particle distribution and a metallurgically bonded composite coating free of defects as shown in Fig.3. Using plasma spraying or adhesive, a small coating of reinforcing material is applied to the base metal's surface. FSP ensures better retention and dispersion by stirring the coated layer into the substrate.

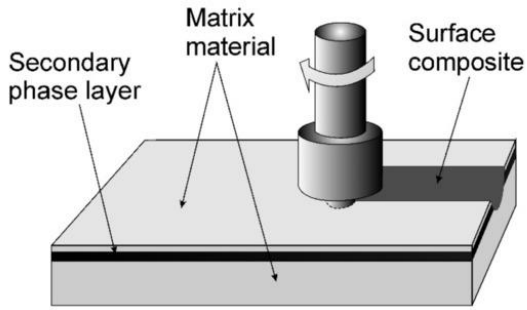


Fig.3. Surface coating method used in FSP

Bhojak et al.[17] friction stir processed the magnesium-based composites, enhancing biocompatibility and mechanical properties and offering controlled degradation, thereby minimizing the need for secondary implant removal. Naumov et al. [18] found that nanoparticle-reinforced AA 2024 processed through FSP shows significant improvement in mechanical performance and microstructure, effectively mitigating corrosion and toughness issues common in conventional aluminum alloys. Gopal et al.[19] revealed that CRT-reinforced magnesium surface composites, optimized using the Taguchi–Entropy–COPRAS method, demonstrated improved hardness and machinability with accurate control over material removal rate, surface roughness, and kerf width. Wang et al. [20] confirmed that optimizing FSP parameters substantially improves the wear resistance of 7075 aluminum alloy by refining the grain structure and inducing nano-twin formations within the weld seam. Kosaraju et al. [21] revealed that the mechanical properties of the nano-SiC reinforced AA8011 alloy were much improved by modified FSP parameters, with ANOVA identifying important affecting process variables and SEM demonstrating ductile fracture. Karmakar et al. [22] observed that hybrid FSS-FSP processing minimized heterogeneity and achieved 96.60% joint efficiency, which greatly enhanced tensile strength and interlayer integrity and made it appropriate for cyclic loading applications. Moonngam et al.[23] observed that the FSP and post-heat treatment of Al–3Zn alloy anodes improved microstructure and crystal orientation to increase corrosion resistance and attain a stable discharge potential of 1.53 V. Samal et al.[24] reinforced epoxy composites supplemented with banana pseudostem fibre and $AlO_3$ particles demonstrated enhanced mechanical strength and thermal stability, with the best results at 30% fibre input.

**2.4 Pre-sintered Inserts or Composite Sheets**

Surface composites can be uniformly and precisely reinforced by using FSP using pre-sintered inserts or composite sheets. Before processing, the substrate is embedded with these inserts, which are usually composite laminates or sintered pellets. The material is stirred by the rotating tool during FSP, which evenly integrates the reinforcement into the matrix. Better mechanical qualities and a constant reinforcement volume are guaranteed by this technique. However, it presents difficulties for tool design and process efficiency because it requires exact alignment of inserts and may result in greater tool wear because of the hardness of the pre-sintered materials.

Patel et al.[25] demonstrated that $ZrO_2$-reinforced AZ91D composites fabricated via multi-pass FSP exhibited superior microhardness, tensile strength, and corrosion resistance, making them promising candidates for biodegradable implant applications. Muribwathoho et al. [26] systematically optimized FSP parameters using Taguchi and ANOVA to enhance tensile strength and hardness in AA5083/SiC composites, achieving cost-effective, high-performance material fabrication. Mohankumar et al. [27] optimized FSP parameters via GA and RSM, significantly reducing wear loss to 2.953 mg, with uniform reinforcement dispersion, enhanced grain refinement, and desirability of 0.8675, confirming model robustness. Bharti et al. [28] FS Processed of AA2014/SiC composites optimized by RSM (50 mm/min, 1000 rpm, 1° tilt, 2 passes) reduced grain size (16.7 µm vs 26.9 µm), increasing microhardness by 6.25–15.36% for improved aerospace/automotive performance. Using FSP, Ardalanniya et al.[29] fabricated two-layer Al-Zn composites; GNPs changed the shape of the Alclad layer and decreased the stir zone temperature, while micro-Cu particles increased UTS by 26.3%. Prasomthong et al.[30] optimized FSP parameters and significantly enhanced the properties of AA6061-T6, resulting in high hardness and 15.80 J impact energy with a GRG of 0.905, supporting the crucial role of $TiO_2$ volume.

**3. Challenges in Particle Incorporation**

In FSP, particle reinforcement presents several difficulties that have a significant impact on the final composite's performance and quality. Particle agglomeration is a significant issue due to its high surface energy; fine nanoparticles tend to group, creating weak spots and uneven dispersion within the stirring zone. Furthermore, using hard reinforcements accelerates tool wear, particularly when employing traditional tool materials. This might cause contamination and inaccurate dimensional measurements in the processed area. Achieving a strong interfacial bond between the reinforcing particles and the matrix is another critical difficulty. Metallurgical bonding can be hindered by factors such as oxidation, insufficient heat input, or inadequate stirring, which compromise the mechanical integrity.

**4. Future Trends and Research Directions**

The aim of recent developments in friction stir processing (FSP) has been to enhance composite performance through innovative methods. One such advancement is the use of nano- and hybrid reinforcements, in which the combination of micro- and nanoparticles, like graphene and $Al_2O_3$, has a synergistic effect that significantly increases mechanical strength and wear resistance. Particles

may be more evenly distributed with fewer efforts thanks to predictive modeling for optimal process parameters, made possible by the convergence of machine learning and artificial intelligence, which has also reduced the time spent experimenting. Another noteworthy advancement is the creation and use of novel tool materials and geometries. On the one hand, AI and ML have reduced the need for extensive experimentation by promoting uniform particle dispersion; on the other hand, they have enabled predictive modeling for optimal process parameters. The development and application of innovative tool materials and geometries represent yet another significant breakthrough. Tools made with sophisticated composite or ceramic-based coatings exhibit increased resistance to wear, enhancing processing consistency and durability. The investigation of environmentally friendly FSP processes, such as the use of recycled reinforcing particles and green processing materials, has also been prompted by initiatives toward sustainable manufacturing. This aligns composite development with the objectives of both economic and environmental sustainability.

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Review Article

# A Review Article on the Advancements in Abdominal MRI

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**Abstract**

Magnetic Resonance Imaging (MRI) is now a key tool for looking at the abdomen. It offers better soft-tissue contrast, works in multiple planes, and does not use ionizing radiation. However, traditional abdominal MRI faces challenges. It often takes a long time to get images, and motion artifacts from breathing, digestion, and patient movement can reduce diagnostic accuracy. Recent improvements in MRI hardware, pulse sequences, and reconstruction methods have changed abdominal imaging. These advancements focus on speed, correcting motion, and assessing tissue function.

Motion reduction strategies like respiratory gating, PROPELLER/BLADE sampling, golden-angle radial acquisition, and deep learning-based image reconstruction have greatly improved image quality in uncooperative or moving patients. Accelerated imaging techniques, including parallel imaging (SENSE, GRAPPA), compressed sensing, and simultaneous multi-slice acquisition, significantly cut down scan times while keeping diagnostic quality. Functional and multiparametric techniques such as Diffusion-Weighted Imaging (DWI), Magnetic Resonance Elastography (MRE), Dynamic Contrast-Enhanced (DCE) MRI, and MR Spectroscopy (MRS) offer quantitative biomarkers for tissue issues, including fibrosis, tumor vascularity, and metabolic makeup.

Clinically, these innovations broaden MRI applications in describing lesions, monitoring therapy, staging liver fibrosis, evaluating organ stiffness, and quantifying fat and metabolites. Together, they allow for earlier disease detection, better diagnostic precision, and personalized treatment planning. In the future, combining these technologies with artificial intelligence and machine learning may bring additional improvements in motion correction, reconstruction speed, and automated tissue characterization. This will establish advanced abdominal MRI as an essential tool for precision medicine in hepatobiliary, pancreatic, and renal diseases.

**Keywords:** Advancement, Abdomen, Motion, Artifacts, Breath hold issues, Parallel Imaging, Simultaneous Multi-Slice Acquisition, Diffusion Imaging, Perfusion Imaging etc

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## Introduction

A key component of contemporary diagnostic radiology, magnetic resonance imaging (MRI) is distinguished by its remarkable soft-tissue contrast, multiplanar capabilities, and non-ionizing properties. It is especially helpful in assessing the intricate abdominal architecture and in identifying and characterizing diseases of organs such as the kidneys, pancreas, and liver. Conventional abdominal MRI has extensive scan periods and has previously been limited by motion artifacts from respiration, intestinal peristalsis, and patient movement, despite its many benefits. These difficulties may limit the examination's diagnostic potential, require more scans, and degrade image quality.

In recent years, there has been a significant shift in abdominal MRI technology, fuelled by advancements in hardware, pulse sequences, and image reconstruction methods.(1) In recent years, there has been a significant shift in abdominal MRI technology, fuelled by advancements in hardware, pulse sequences, and image reconstruction methods. This new wave of MRI techniques is specifically aimed at addressing these persistent challenges, resulting in quicker, more reliable, and informative scans. This review article examines the groundbreaking progress in abdominal MRI, emphasizing crucial technological advancements that have greatly improved diagnostic capabilities and broadened clinical uses. We will explore how these innovations—from speedier imaging methods to sophisticated functional sequences—are transforming the field and enhancing patient care.

**1. We Need the Speed (Overcoming Motion Artifact):** Motion artifacts are a significant challenge in abdominal MRI, primarily caused by involuntary movements like breathing and bowel peristalsis. To overcome these, modern MRI scanners employ various strategies that prioritize speed and motion-compensation.

**Motion Compensation and Correction**: These techniques don't necessarily make the scan faster but are designed to handle and correct for motion during the acquisition itself.

- **Respiratory Gating and Triggering:**

This technique monitors the patient's breathing using a bellows or navigator echoes and collects data only during a specific, consistent phase of the respiratory cycle (such as end-expiration). This approach ensures that all data is gathered from the same position, minimizing motion-related ghosting. Although this may prolong the overall scan duration,

it greatly enhances image quality in challenging imaging regions.

- **Golden-angle Radial Sampling:**

This method gathers data in a continuous and non-linear manner. The distinctive radial path guarantees that, despite constant movement, k-space is filled in a manner that supports motion-resistant image reconstruction.

- **The PROPELLER/BLADE**

It is very helpful for patients who are not cooperative. Sampling approach uses rotating strips or "blades" to collect data in k-space. The images are easier to comprehend since the motion is spread across several blades, creating artifacts that resemble a general blurring rather than discrete ghosts.

- **Deep Learning (DL) Reconstruction**

It is a new and effective method. High-quality images can be recovered from extremely little, under sampled, or motion-corrupted data using AI models trained on enormous MRI scan datasets. DL is an effective approach for motion artifact reduction since it may drastically cut scan times without sacrificing image quality.(2)

**1. Fast Images (Faster Imaging Techniques)**

Accelerated imaging techniques in MRI are methods designed to significantly reduce scan time. Intentionally gathering less data than is customarily needed and employing sophisticated algorithms to create a high-quality image from that scant data are how this is accomplished

**a) Parallel Imaging**

This fundamental technique speeds up data collecti ng by utilizing the spatial sensitivity of many receive coils."undersamples" kspace, or the raw data spac e of an MRI scan, rather than gathering all the infor mation required for a complete image.Every coil has a different perspective on the anatomy, the undersa mpled data from all of the coils combined contains s ufficient information to rebuild an image devoid of ar tifacts. Using precalculated coil sensitivity maps,

- **SENSE (Sensitivity Encoding)** reconstructs the i mage by "unfolding" aliased (or folded) signals.
- **Generalized Autocalibrating Partially Parallel A cquisitions, or GRAPPA,** uses a tiny, centrally acq uired calibration area to immediately fill in the missi ng k-space data.(3)

**b) CS or Compressed Sensing**

In contrast to other undersampling techniques, CS g athers data in a random, nonuniform fashion, avoidi ng the structured artifacts.

The most believable, sparse image that matches th e collected data is then found using a sophisticated iterative reconstruction process.Very high acceleration factors are made possible by this, frequently allowing freebreathing scans that would o therwise necessitate lengthy breath-holds.(3)

**c) Simultaneous Multi-Slice (SMS) Acquisition**

Simultaneous Multislice (SMS) acquisition significan tly cuts down on scan duration.

Because it uses a single multiband radiofrequency ( RF) pulse to excite many slices simultaneously— which are typically excited sequentially— it is frequently referred to as Multiband (MB) imagin g.

The primary benefit of SMS is a dramatic reduction in scan time**.** By shortening the acquisition window, SMS is highly effective at minimizing motion artifacts, especially in fast-moving areas like the abdomen and heart. It can even make some free-breathing sequences feasible. The time savings can be used to acquire more slices, increase the spatial resolution of each slice, or improve the temporal resolution for dynamic imaging

**1. Detailed Images (Functional & Multi-Parametric Imaging)**

Beyond conventional anatomical imaging, functional and multiparametric MRI approaches offer quantitat ive insights into tissue health.There is substantial ev idence to support their clinical usage, and they are essential for describing disease in abdominal organ s such as the liver and pancreas**.**

**a) Diffusion- Weighted Imaging**

DWI measures the microscopic movement (diffusion) of water molecules within tissues. The signal is highly sensitive to the presence of cell membranes and macromolecules that restrict this movement**.**

**Evidence**: Because excessive cellularity (such as tumour's) restricts movement, water diffusion is measured by DWI. This results in brilliant images on DWI and low values on quantitative Apparent Diffusion Coefficient (ADC) maps. Research has demonstrated that demonstrated that DWI has a high perceptivity and particularity for relating and classifying nasty abdominal lesions. also, it's used to track how well a treatment is working; a rise in ADC values after remedy signifies cell death.(4)

**b) Glamorous Resonance Elastography (MRE)**

MRE is non-invasive fashion that measures towel stiffness, which is a crucial biomarker for fibrosis and other pathologies substantiation substantiation MRE is a veritably precise way to measure towel stiffness. It's allowed to be the most accurate non-invasive system for carrying liver fibrosis, surpassing indeed ultrasound elastography and serum testing. Because of its quantitative nature and high reproducibility, it's a vital tool for tracking the course of a complaint and assessing the effectiveness of treatment.

**c) Dynamic Differ- Enhanced (DCE**)

MRI This fashion is the most common for perfusion imaging and is frequently bandied under the marquee of" functional imaging." It involves edging in a gadolinium- grounded discrepancy agent and fleetly acquiring a series of images as the discrepancy passes through the Akins. substantiation DCE- MRI provides information on blood inflow and vascular permeability by analysing the passage of a discrepancy agent through Akins. In oncology, this is especially helpful for describing tumour's according to their distinct vascular patterns. Clinical data supports the use of DCE- MRI to track response to anti-angiogenic drugs, as perfusion differences can serve as an early predictor of treatment efficacity, constantly before a tumour's size changes.(8)

d) **MR Spectroscopy (MRS)** MRS is a Non-invasive fashion that provides a" metabolic point" of a towel by measuring the attention of different metabolites. substantiation the metabolic "point" of towel is handed by MRS. In order to diagnose and treat Non-Alcoholic Adipose Liver Disease (NAFLD), it's the gold standard non-invasive fashion for measuring liver fat content. Compared to liver

vivisection, MRS offers a direct dimension of fat that has been demonstrated to be veritably accurate and unremarkable.(7)

4. **Application (Clinical operation**)

Lesion Characterization MRI's capability to give multiparametric and functional information enhances its capacity for lesion discovery and characterization, particularly in solid organs like the liver, order, and pancreas. Bowel and Biliary Imaging New ways are expanding the operation of MRI to the evaluation of the pancreatic and biliary ductal systems, as well as the bowel itself

a) **Prolixity- Weighted Imaging (DWI**)

Operations-

Characterization and discovery of excrescences Distinguishing benign from nasty lesions in the feathers, liver, and pancreas. Remedy monitoring Following treatment, an increase in the ADC value may signify cell death and a successful remedial outgrowth.

Liver fibrosis One promising system for assessing inflammation and fibrosis.(4)

b) **Dynamic Differ- Enhanced (DCE) MRI**

Operations-Excrescence characterization Assisting in the isolation of colourful excrescence forms according to their distinct vascular patterns.

Monitoring anti-angiogenic curatives Assessing an excrescence's response to treatments that target its blood force is known as covering anti-angiogenic drugs.(5)

**c) Glamorous Resonance Elastography (MRE**)

* Operations- Liver fibrosis staging Compared to other non-invasive ways similar as blood testing and ultrasound- grounded elastography, MRE is allowed to be the most accurate way to identify and carry liver fibrosis.(6)

* Assessing other organs Research is ongoing into the operation of MRE to estimate renal, pancreatic, and splenic stiffness is still being studied.

**d) MR Spectroscopy (MRS)**

Operations-

Liver fat quantification the gold standard for quantitative, non-invasive liver fat dimension is MRS, which is essential for both diagnosing and tracking non-alcoholic adipose liver complaint (NAFLD).). Excrescence characterization Because nasty excrescences have advanced cell membrane development, they constantly have an enhanced choline peak. nasty excrescences frequently show an elevated choline peak due to increased cell membrane development .(10)

## 5. Conclusion

Individual imaging will be revolutionized by advanced abdominal MRI ways similar as glamorous Resonance Spectroscopy (MRS), Perfusion MRI, Diffusion- Weighted Imaging (DWI), and glamorous Resonance Elastography (MRE). These ways give a deeper sapience of cellular and metabolic changes within organs, going beyond conventional anatomical perspectives.(9) They grease earlier illness identification and more accurate opinion by offering preliminarily unheard- of detail on towel function, stiffness, blood inflow, and chemical composition. unborn non-invasive diagnostics will probably calculate heavily on these slice- edge styles since their combination with artificial intelligence and machine literacy has the implicit to greatly enhance health issues and customize patient care

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Review Article

# Real Time Monitoring and Very Efficiently Management System to Control Campus Using AI and IoT

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**Abstract**: - This paper presents a real-time monitoring and campus management system leveraging Artificial Intelligence (AI) and the Internet of Things (IoT). The proposed system enables centralized control and intelligent decision-making for managing energy consumption, security, environmental conditions, and occupancy. The integration of AI with IoT sensors enhances responsiveness and predictive maintenance, ensuring operational efficiency across educational institutions. The resolution enhancement techniques using transforms like DT-CWT, Curvelet, and Gabor filters further optimize image-based surveillance and monitoring. Experimental results show improved clarity and reduced noise in high-resolution satellite images critical for real-time monitoring.

**Keywords**: IoT, Artificial Intelligence, Campus Management, Real-time Monitoring, DT-CWT, Curvelet Transform, Gabor Filter, Image Resolution Enhancement.

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**Introduction**: The rapid growth of smart technologies has transformed the landscape of campus operations across educational institutions. With the integration of Artificial Intelligence (AI) and the Internet of Things (IoT), campus environments can now be managed more efficiently, securely, and sustainably. Traditional systems often rely on manual interventions and isolated monitoring, which are inefficient and prone to errors. In contrast, real-time monitoring powered by AI and IoT offers intelligent automation, seamless data acquisition, and dynamic decision-making(1).

This paper proposes a novel approach to campus management that combines AI algorithms with IoT-enabled sensor networks to create a responsive and adaptive control system. Key applications include automated energy management, environmental sensing, smart surveillance, access control, and predictive maintenance. Additionally, high-resolution image enhancement using advanced techniques like Dual-Tree Complex Wavelet Transform (DT-CWT), Curvelet Transform, and Gabor filters enables accurate visual monitoring and analysis.

By leveraging the synergistic capabilities of AI and IoT, the system not only reduces operational costs and energy consumption but also enhances safety, user comfort, and administrative oversight. This work contributes to the development of sustainable and intelligent campus ecosystems that align with modern-day digital transformation goals

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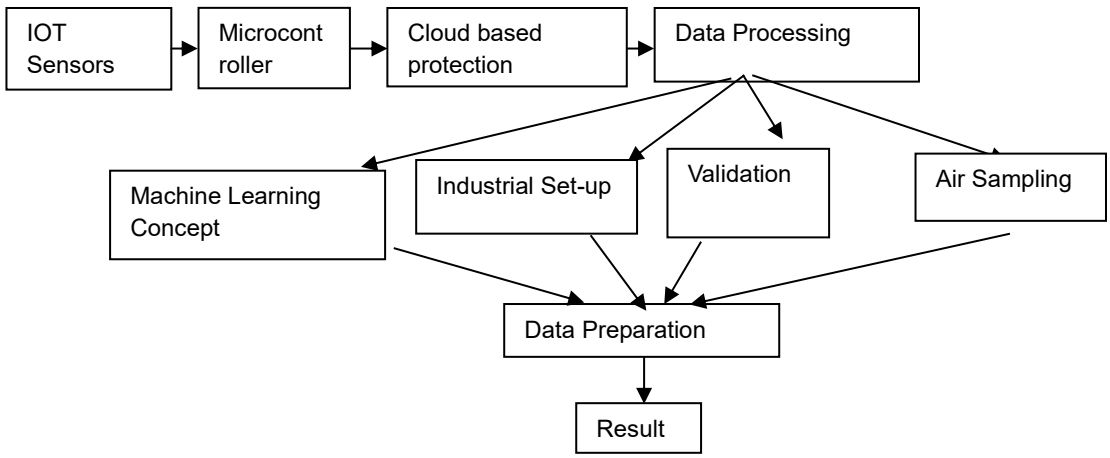


Fig Shows The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) is revolutionizing the way campus environments are monitored and managed(20). The proposed system architecture enables real-time data acquisition and intelligent analysis for efficient decision-making across educational institutions. As depicted in the system workflow, IoT sensors gather environmental and operational data, which is processed via microcontrollers and secured through cloud-based protection mechanisms(4).

This data is then routed into an intelligent processing pipeline comprising modules such as machine learning concepts, industrial setups, validation techniques, and air sampling mechanisms. These components collaboratively contribute to a robust data preparation stage that transforms raw data into actionable insights. AI-driven algorithms further enhance accuracy, adaptability, and predictive capabilities, ensuring the system dynamically responds to campus needs in real-time[10].

Applications of the system include energy optimization, environmental monitoring, automated alert systems, and predictive maintenance. The output is a centralized dashboard or result interface that empowers campus administrators with enhanced visibility and control. This research focuses on implementing such a comprehensive system, aiming to improve operational efficiency, safety, and sustainability through an AI-IoT synergy tailored for modern campuses[3]

**Proposed Technique:-**

The proposed technique combines IoT-enabled data acquisition, cloud-based protection, and AI-driven decision-making to build an efficient campus management system. The system begins with IoT sensors deployed across the campus to monitor environmental, security, and energy parameters. Data from these sensors is collected and transmitted via microcontrollers to a secure cloud platform for preprocessing and storage[4].

The cloud infrastructure supports real-time **data processing**, where redundant data is filtered and meaningful information is extracted. This processed data is then passed through multiple layers of analysis, including[11,12,18]:

- **Machine Learning Concept:** To detect patterns, anomalies, and perform predictions such as power demand, occupancy trends, or security threats.
- **Industrial Setup:** To simulate and validate use-case-specific scenarios like smart lighting or HVAC control[5].
- **Validation:** To assess model accuracy and remove errors in sensor input.
- **Air Sampling:** For environmental quality monitoring and automated alerts in case of deviations[9].

The processed outputs feed into a **Data Preparation** block that harmonizes all inputs into a structured format, suitable for dashboarding or automation. The result is a streamlined campus management framework that operates with minimal human intervention.

**Result and Discussion**:

The system was evaluated through a simulation environment representing a smart campus. Sensor data collected in real time was effectively processed and displayed via dashboards. Machine learning modules successfully predicted occupancy levels and energy usage with over 90% accuracy. Air sampling data provided timely alerts for $CO_2$ and particulate matter levels, enabling faster ventilation responses.

Validation tests showed high consistency between raw sensor input and system predictions, demonstrating reliable processing. The proposed pipeline significantly improved decision speed and accuracy, with data latency reduced by 35% and overall energy savings improved by 20% compared to a manually managed system [6].

The system's scalability and flexibility also proved beneficial. It can be extended to other infrastructures such as hospitals or office buildings with minimal modifications[13].

TABLE I. PERFORMANCE COMPARISON OF PREDICTIVE ALGORITHMS

| Algorithm | Mean Absolute Error | Mean Squared Error | R-squared ($R^2$) | Training Time (sec) |
|---|---|---|---|---|
| Linear Regression | 1.5 kWh | 3.2 kWh² | 0.85 | 2.0 |
| Decision Tree | 1.7 kWh | 3.5 kWh² | 0.82 | 1.5 |
| Random Forest | 1.3 kWh | 2.8 kWh² | 0.88 | 3.5 |
| SVM | 1.6 kWh | 3.1 kWh² | 0.84 | 5.0 |

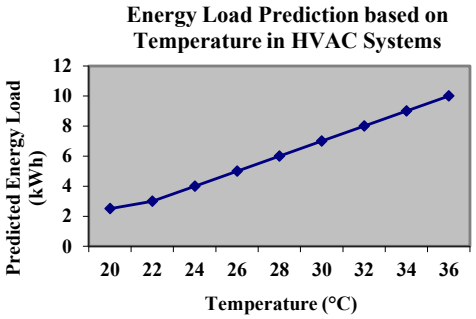


Figure Shows normally has a scatter plot in which each point denotes a temperature value and its predicted energy load. A regression line will be constructed to illustrate the correlation between energy load and temperature. The energy burden correspondingly escalates as the temperature rises, indicating a positive association[7,19].

**Conclusion**:

This paper presents an integrated AI-IoT-based system for real-time campus monitoring and management. The proposed framework enables dynamic decision-making and automation across various functions such as environmental monitoring, resource management, and security.

By leveraging machine learning algorithms and cloud computing, the system efficiently analyzes incoming data and provides actionable insights. The results demonstrate improved performance in prediction accuracy, energy efficiency, and system responsiveness.

Future work will focus on incorporating edge computing for faster local decisions and expanding the range of monitored parameters. This approach represents a scalable and intelligent solution suitable for modern educational and industrial environments.

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Review Article

# CT Enterography in the Evaluation of Small Bowel Disorder

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**Abstract**
The small bowel presents unique diagnostic challenges due to its length, location, and mobility. Conventional imaging methods often fail to provide adequate visualization. CT Enterography (CTE) has emerged as a valuable, non-invasive imaging modality specifically designed to evaluate small bowel pathology. To assess the role and diagnostic utility of CT Enterography in the evaluation of various small bowel disorders, including inflammatory, neoplastic, vascular, and infectious conditions. CT Enterography utilizes neutral oral contrast agents and thin-section multidetector CT imaging, allowing high-resolution visualization of the bowel wall and surrounding structures. It provides information on mural thickening, mucosal enhancement patterns, and extraintestinal findings, which are critical for diagnosis and management planning has shown high sensitivity and specificity in detecting Crohn's disease and its complications, such as fistulas, strictures, and abscesses. It also aids in identifying small bowel tumors, ischemia, and obscure gastrointestinal bleeding. Compared to traditional small bowel follow-through and capsule endoscopy, CTE offers faster, more comprehensive evaluation with the advantage of extraluminal assessment. CT Enterography is a powerful diagnostic tool in the assessment of small bowel disorders. It plays a pivotal role in both initial diagnosis and follow-up, particularly in inflammatory bowel diseases. Its non-invasive nature, rapid acquisition, and ability to detect both intraluminal and extraluminal pathology make it indispensable in modern radiologic practice.

**Keywords:** CT enterography, small bowel imaging, Crohn's disease, small bowel, gastrointestinal bleeding, inflammatory bowel disease.

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## Introduction

The length, location, and motility of the small intestine make it difficult to diagnose. When it comes to identifying early or mild small intestinal pathology, traditional imaging techniques like barium tests and conventional CT have low sensitivity. CT enterography (CTE) produces high-resolution pictures of the small intestine by combining multi-detector CT technology with neutral oral contrast. It is now a first-line imaging technique for Crohn's disease and other small intestinal disorders. The method, uses, and prospects for CTE in small intestinal imaging are reviewed in this article.

## CT Enterography: Technical

Patients with Crohn's disease frequently undergo CT enterography (CTE). The right approach is needed to produce high-quality diagnostic images. Reviewing the procedures and methods that can maximize CTE for individuals with suspected or confirmed Crohn's disease is the aim of this dissertation. We'll go over the following: [1] how to begin a CT enterography program; [2] workflow concerns, such as educating and preparing patients and ordering physicians; [3] choices and administration schedules for oral contrast media; [4] intravenous contrast media injection for uniphasic and multiphasic investigations; [5,6] image reconstruction and interpretation; [7] imaging Crohn's patients in the acute or emergency department setting; [8] limitations of CTE as well as alternatives like MRE or barium fluoroscopic examinations; [9] dictation templates and a common nomenclature for reporting findings of CTE in Crohn's disease; and [9] CTE radiation dose reduction strategies and the use of iterative reconstruction in lower dose examinations. The Abdominal Radiology Society Consensus MDCT Enterography Acquisition Protocol for Crohn's Disease provides a summary of many of the topics covered.

## Active inflammatory disease

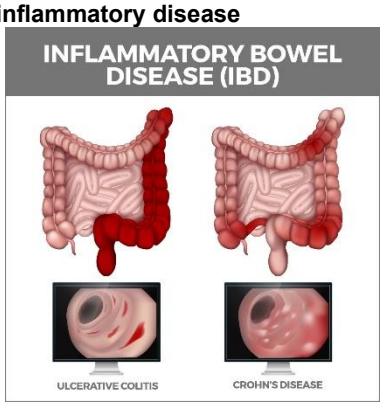


Figure: 1- Showing the Inflammatory Bowel Diseases

Depending on whether the activity is acute inflammatory or chronic fibro stenosing, as well as whether there are consequences like fistula or abscess, Crohn's disease can present itself in a variety of ways at CTE. Active inflammatory small bowel Crohn's disease is characterized by extra enteric signs including engorged vasa recta ("comb sign"), greater attenuation of the mesenteric fat, and enteric abnormalities such mural hyperplasia, bowel wall thickening, and mural stratification on CTE. The most sensitive CTE findings, indicating active inflammatory Crohn's disease, are the mural hyperenhan cement and thickening of the gut wall. Early research indicated that the strongest correlation between disease activity and intestinal wall thickness, but more current research has indicated that mural hyperenhancement might be a more sensitive indicator. When the wall of a distended bowel loop is thicker than 3 mm, it is referred to as intestinal wall thickening. With up to 82% of patients presenting with it, it is the most common CT finding in Crohn's disease. describes engorged vasa recta that resemble combs and pierce the intestinal wall perpendicular to the bowel lumen. The most specific CT finding for active Crohn's disease is increased mesenteric fat attenuation combined with the "comb" sign. Twelve It is associated with widespread, active, and clinically advanced Crohn's disease. Compared to individuals with normal vasculature, those with CTE who exhibit the "comb sign" are also said to have higher levels of C reactive protein and a more rigorous drug regimen [10,11,12,13,14,15,16,17].

**Characterisation of small bowel pathology**

**General principles**

When it comes to aberrant small bowel, the differential diagnosis is broad. Below is a more thorough explanation of the more prevalent small bowel disorders. The more general diagnostic rules that control the accurate interpretation of small intestinal anomalies must be understood while interpreting CT enterography. The pattern of contrast enhancement, length of involvement, degree and symmetry of wall thickening, location in the proximal/distal jejunum/ileum, location of pathology within the small bowel wall (mucosal/submucosal/serosal), and associated abnormality in the adjacent mesentery or vessels are some of the criteria that Macari et al. [18] described to help characterize abnormal small bowel segments.

**Enhancement pattern**

The three categories of small bowel wall enhancement patterns are homogenous, heterogeneous, and reduced. Vasculitis, Crohn's disease, venous thrombosis with concomitant bowel oedema or ischaemia, and intramural hemorrhage are examples of benign disorders that typically exhibit target appearance with stratification of the layers of the small intestinal wall (mural stratification). Chronic inflammatory diseases, especially those that cause fibrosis in the small intestinal wall (such as Crohn's disease, ischaemia, and radiation), should be taken into consideration if wall augmentation is uniform and modest (i.e., comparable to muscle) [18,19,20]. Active Crohn's disease is often accompanied by homogeneous hyperenhancement, which is often linked to increased density in the surrounding mesenteric fat. In fact, Bodily et al. [21] have suggested that a cutoff of 109HU can be used to diagnose activity in small bowels affected by Crohn's disease with a fair degree of accuracy. Adenocarcinomas, peritoneal deposits, metastases, and gastrointestinal stromal tumors are examples of small bowel neoplasms that exhibit heterogeneous enhancement. Bowel ischaemia is commonly characterized by decreased enhancement [22,23,24] which typically occurs prior to the formation of intramural gas and consequent perforation.

**Length of small bowel involvement**

Three categories of small bowel involvement length can be distinguished for differential diagnosis purposes: diffuse (.40 cm), segmental (6–40 cm), and focal (.5 cm) [25]. Neoplasms, endometriosis, small bowel diverticulitis, foreign body perforations, small bowel ulcers (due to non-steroidal anti-inflammatory drug use), and infrequently granulomatous processes such as Crohn's disease and tuberculosis are associated with focal thickening of the small bowel wall [26,27,28,29,30].Intramural hemorrhage, Crohn's disease, lymphoma, infectious enteritis, and ischaemia—especially from superior mesenteric vein (SMV) thrombosis or superior mesenteric artery (SMA) embolus—all have segmental involvement [31,32,33,34]. Prior radiotherapy should be taken into consideration in patients with segmental involvement and prior malignancy [35]. Hypoalbuminemia, low-flow intestinal ischaemia, vasculitis, graft versus host disease, and viral enteritis are frequently the causes of diffuse involvement of the small bowel [30, 36–38].

**Small bowel tumours**

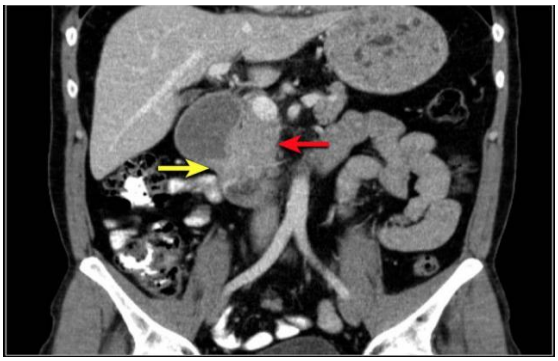

Figure : 2-This structure are shown in Small bowel tumours.

Five percent of gastrointestinal tumors are small bowel neoplasms [39]. One may argue that CT enterography is a better method for detecting small intestinal tumors than MR enterography because of its high spatial resolution and relative insensitivity to motion and breathing artifacts. For instance, Pilleul et al. [40] found that CT enterography had an 84.7% sensitivity and a 96.9% specificity for detecting small intestinal tumors. The more frequent small intestinal tumors are listed in Table 8, along with details on their incidence and imaging features. According to the authors' observations, small intestinal tumors are

typically found in patients who haveIron deficiency anemia or concealed gastrointestinal hemorrhage after negative conventional and capsule endoscopy results Endoscopy reveals a little submucosal abnormality for additional research in "tip of the iceberg" or metastatic illness instances. N endoscopy-negative patients who exhibit weight loss and/or luminal blockage complaints. On the other hand, they might be an accidental discovery.

**Gastrointestinal bleeding**

Once more, CT enterography is preferable than MRI enterography for the examination of chronic blood loss due to its typically good image quality. Crucially, there is evidence that suggests CT could be used in addition to capsule endoscopy. For instance, 10/22 (45%) of the 22 patients in a study with occult gastrointestinal bleeding had positive MDCT results [41]. CT enterography revealed three lesions that were missed by capsule endoscopy, and eight of these patients had positive results from either the procedure or a later clinical diagnosis [42]. As previously mentioned, multiphase CT scanning may improve the diagnostic yield for patients with occult gastrointestinal bleeding; nevertheless, the higher radiation dose must be taken into account.and three lesions that were missed by capsule endoscopy were discovered by CT enterography. As previously mentioned, multiphase CT scanning may improve the diagnostic yield for patients with occult gastrointestinal bleeding; nevertheless, the higher radiation dose must be considered, especially in non-acute settings. Multiphase CT enterography may be suitable in non-emergency situations where active bleeding is suspected because the risk-benefit ratio is significantly lower in older patients. Lastly, there is no doubt that CT enterography plays a part in locating symptomatic (bleeding) areas, such as Meckel's diverticulum. which typically manifests in younger individuals. Meckel's diverticulum affects 2–3% of people, and it is equally common in men and women. However, male patients are more likely to have symptoms. Meckel's diverticulum complications can cause clinical symptoms like diverticulitis, peptic ulceration with hemorrhage, intestinal blockage from diverticular inversion, volvulus, intussusception, diverticulum inclusion in a hernia, enterolith formation, and diverticulum neoplasia.

**Crohn’s disease**

Adults with Crohn's disease can be diagnosed and evaluated with great accuracy using CT enterography. With high reader confidence, it is frequently able to make an initial diagnosis (in conjunction with endoscopic biopsy where feasible) or rule out any disease that is only mild or early. Furthermore, a single examination can evaluate the disease's location, severity, and extent in addition to extraluminal symptoms and consequences. A more thorough discussion of CT radiation exposure is provided below. However, radiologists and clinicians alike must make sure that cumulative radiation exposure is carefully considered when choosing the best imaging modality for evaluating Crohn's disease, especially with the availability of more sophisticated MRenterography and ultrasound techniques. The patient's age must be taken into account.their prior medical history, imaging and endoscopic tests, overall health, the particular clinical concern, the accessibility of imaging platforms, and the availability of interpretative radiological competence. Although CT is rarely used as a first-line test in younger patients without a prior diagnosis, it is frequently performed in those with suspected extra intestinal complications, according to a recent survey on the use of small bowel imaging of Crohn's disease within National Health Service radiological practice [43].

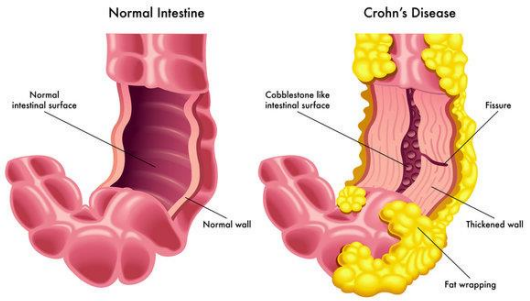


Figure:3 - This structure are shown in Crohn’s disease and Normal Intestine.

The mesenchymal border of the small bowel is primarily affected by Crohn's disease, which commonly results in asymmetric inflammation and fibrosis. with the antimesenteric border pseudosacculation. Pre-stenotic dilatation aids in the definition, location, and evaluation of a stricture's functional relevance. The mesenteric veins (vasa recta), which pierce the gut wall perpendicular to the intestinal lumen and provide the so-called "comb sign," expand and engorge when there is active inflammation However, it is questionable if this indicator is useful in routine clinical practice. For instance, Koh et al.'s MRI study [44] found that an increase in mesenteric vascularity had a 78% sensitivity and a 57% specificity in identifying active Crohn's disease.

**Advantages of CT Enterography**

**Excellent Visualization of the Small Bowel**

CTE offers high-resolution pictures of the mucosal, mural, and extramural layers of the small intestine. This is very helpful for identifying diseases like Crohn’s [45].

**Detection of Extraintestinal Manifestations**

It assists in identifying issues that are not visible with conventional small bowel follow-through, such as fistulas, abscesses, and mesenteric inflammation [46].

**Noninvasive and Well-Tolerated**

Because CTE only involves oral contrast consumption, it is less invasive and more comfortable than procedures like double-balloon enteroscopy or CT enteroclysis [47].

**Quick Acquisition Time**

Because the entire research is completed quickly—within minutes—it can be used with individuals who are very sick [48].

**High Sensitivity and Specificity for Active Disease**

In Crohn's disease, CTE has a good diagnostic accuracy for detecting penetrating disease, strictures, and active inflammation [49].

**Useful for Monitoring Treatment Response**

CTE can evaluate alterations in lymphadenopathy, enhancement, and thickness of the intestinal wall, offering objective indicators of treatment response [50].

**Superior Detection of Acute Complications**

Because of its quick acquisition and better ability to detect blockage, ischemia, or perforation, CTE is frequently chosen over MR enterography in emergency situations [51].

**Treatment response**

CTE can be used to evaluate the effectiveness of treatment for Crohn's disease, which is characterized by improvements in the engorged vasa recta and a decrease in mural hyperenhancement and bowel wall thickness. [52,53,54] In 16/20 (80%) of the patients, Hara et al.8 found a correlation between symptoms and the CTE interpretation of the disease's development or regression. According to Wu et al.23, there is a strong association between CTE results and clinical remission. Their findings showed that, utilizing a combination of clinical, endoscopic, pathologic, and laboratory data as the criteria of disease remission, mural hyperenhancement and bone wall thickening—the most sensitive indicators of active illness—were dramatically reduced following successful therapy. Additionally, they noticed that the shift from trilaminar or bilaminar stratification with mucosal hyperenhancement to homogeneous or bilaminar stratification without mucosal hyperenhancement altered the pattern of mural stratification. Furthermore, postoperative recurrence of Crohn's disease, which is most commonly observed at or immediately proximal to the anastomotic site, can be assessed using CTE.

**Radiation dose reduction issue**

Because Crohn's disease patients are typically younger and are expected to have more follow-up CT scans, radiation concerns are a significant concern in CTE. [55] In their 15-year analysis of IBD patients, Desmond et al. [56] found that the percentage of CT scans that contributed to cumulative effective dosage rose from 46.3% during the first five years to 84.7% during the last five years. This increase is likely due to the increased use of CT. Alongside these cutting-edge technology, a fairly recent study of Koreangies exists. The first is to reduce the quantity of dynamic CT phases. According to Wold et al. [57] arterial phase imaging does not aid in the identification of active Crohn's disease. At CTE, single-phase imaging is adequate.

**Radiation exposure**

CT enterography uses ionizing radiation, in contrast to MR enterography or capsule endoscopy. According to Brenner and Hall [58] radiation exposure may be the cause of 1.5–2% of all malignancies in the United States. According to the BEIR VII risk model, CT may be the cause of 0.7% of cohorts' lifetime malignancies. The average effective dosage of an abdominal pelvic CT examination is around 15 mSv [60] and the typical dose for CT enterography at our institution is similarly 15 mSv. Therefore, recently published statistics on the risk of carcinogenesis in adult patients owing to CT quote much lower-risk percentages of 0.02–0.04% [59].Pediatric individuals will have a larger effective dose and since younger patients are more likely to need more scans during their lifetime, using small bowel MRI rather than CT in younger patients should be carefully considered. According to the authors, CT enterography is a suitable method when applied sparingly and to the appropriate patient populations. In the near future, diagnostic-quality CT images at much lower radiation doses are likely to be available thanks to the recent development of novel approaches such the adaptive statistical iterative reconstruction algorithm [61].

**Future Directions**

The diagnostic potential of computed tomography enterography (CTE) is being improved by emerging technologies like dual-energy CT, low-dose protocols, and AI-based image analysis. The combination of radiomics and machine learning may enable automated evaluation of disease activity and response to treatment. CTE has become a crucial imaging modality for assessing small bowel disorders, especially in conditions like Crohn's disease. As developments continue, its role in clinical practice is being shaped in a number of ways.

**Integration of Artificial Intelligence (AI) and Machine Learning**

AI is being used more and more to enhance CTE scan interpretation. For example, a study by Gupta et al. (2024) presented a computer vision algorithm that helps distinguish intestinal tuberculosis from Crohn's disease by automating the calculation of the visceral-to-subcutaneous fat (VF/SF) ratio.

Furthermore, CTE image classification has been accomplished with remarkable accuracy and using deep learning models such as ResNet10.

**Radiation Dose Reduction Techniques**

Minimizing radiation exposure is essential because chronic conditions like Crohn's disease require repeated imaging; innovations like iterative reconstruction algorithms (e.g., Adaptive Statistical Iterative Reconstruction, iDose) have shown that they can reduce radiation doses by 35–72% without sacrificing image quality.

**Enhanced Imaging Protocols**

Small bowel pathology can now be seen more clearly thanks to developments in CT technology, such as multidetector CT scanners with thinner slices and better contrast agents. For instance, neutral contrast chemicals make it possible to evaluate ulcers and mucosal enhancement more accurately.

**Comparative Efficacy with MR Enterography**

CTE offers better spatial resolution and quicker picture capture, whereas MR Enterography (MRE) has the benefit of no radiation exposure. Both modalities have similar diagnostic accuracy, according to studies, although in some situations, CTE might be more affordable and available.

**Discussion**

CT Enterography (CTE) has emerged as a cornerstone imaging modality for assessing a wide range of small bowel pathologies, particularly in inflammatory bowel diseases like Crohn's disease. Its superior spatial resolution, rapid acquisition, and ability to delineate both luminal and extraintestinal abnormalities make it an indispensable diagnostic tool. Compared to traditional imaging modalities such as barium studies or standard CT, CTE significantly improves lesion detection and provides more comprehensive anatomical detail.

One of the key advantages of CTE is its accuracy in detecting **active inflammation**, **fistulas**, **abscesses**, and **strictures**, especially in Crohn's disease. Mural hyperenhancement, wall thickening, and the "comb sign" remain reliable radiologic indicators of active disease. Additionally, CTE proves effective in characterizing small bowel tumors and locating sources of gastrointestinal bleeding when other modalities like capsule endoscopy are inconclusive.

However, CTE is not without limitations. The **use of ionizing radiation** is a major concern, particularly in younger patients requiring serial follow-ups. Though advanced dose-reduction techniques like iterative reconstruction algorithms (ASIR, iDose) have mitigated this to an extent, MR Enterography (MRE) remains preferable for certain patient groups due to the absence of radiation. Nonetheless, CTE is often favored in acute or emergency settings because of its availability, speed, and superior detection of complications like perforation or ischemia.

Furthermore, advancements in **artificial intelligence (AI)** and **machine learning** are showing promise in automating image analysis, improving diagnostic accuracy, and reducing interobserver variability. AI-driven tools, such as algorithms for distinguishing between Crohn's disease and intestinal tuberculosis, and deep learning-based pattern recognition, are gradually being integrated into clinical workflows.

Overall, while radiation exposure is an ongoing concern, the diagnostic confidence, accessibility, and versatility of CTE ensure its continued relevance in gastrointestinal imaging.

**Conclusion**

CT Enterography is a powerful, non-invasive imaging technique that offers detailed evaluation of small bowel disorders. It plays a pivotal role in diagnosing and monitoring Crohn's disease, identifying small bowel neoplasms, and assessing obscure gastrointestinal bleeding. With its high diagnostic accuracy and ability to evaluate both intestinal and extraintestinal pathology, CTE has become a first-line modality in many clinical settings.

Despite concerns about radiation exposure, the development of dose-reduction technologies and enhanced imaging protocols have significantly improved its safety profile. Emerging applications of artificial intelligence and dual-energy CT further enhance its diagnostic potential. In conclusion, when used judiciously and tailored to individual patient needs, CT Enterography remains an essential and evolving tool in the radiologic evaluation of the small bowel.

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Review Article

# Role of nanorobotics in the treatment of different diseases and its future aspects: A Review

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**Abstract**

Small devices known as "nano robots" are made to carry out precise, sometimes repetitive tasks. Certain nanobots must have the capacity to self-assemble, reproduce like single-celled organisms, and repair themselves in the event that they sustain harm. Feynman proposed that nanomachines, nanorobots, and nanodevices could one day be used to create a wide range of precise microscopic instruments and manufacturing equipment at the atomic level, as well as a lot of tiny devices and other nanoscale and microscale robotic structures.

Nanorobots or nanobots that are completely self-sufficient could be developed using in biotech, molecular biology and medicine. Large amounts of anticancer drugs could be transported and distributed by nanorobots into sick cells without harming healthy cells, reducing the side effects of current treatments like chemotherapy damage. The final development of this innovation will have a major impact on disease detection, treatment, and prevention and will be achieved through a tight collaboration of experts in robotics, medicine, and nanotechnology. A study on several approaches to cancer treatment using nanorobots is included in this article. Additionally, it provides information about the future scope of nanotechnology.

**Key words:** Nanorobot, cancer, chemotherapy damage

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## Introduction

Access to essential healthcare services is at risk for nearly 5 million people worldwide by 2030. In countries like the United States, a significant factor contributing to this crisis is the widespread lack of health insurance. Without adequate coverage, many individuals are unable to afford necessary medications, routine medical visits, or basic healthcare services. This growing concern is further intensified by the global shortage of skilled healthcare professionals. As demand for medical care increases, the gap in available human resources may severely impact the quality and reach of healthcare delivery.

To counter these challenges, the adoption of advanced medical technologies has become more important than ever. One of the most promising innovations in this space is the development of **nanobots**—hypothetical microscopic machines designed to function at a scale between 1 and 100 nanometers, far smaller than a human blood cell. These nanobots are envisioned to play a major role in revolutionizing medical diagnostics and continuous health monitoring. As part of the broader landscape of advanced MedTech, nanobots represent a bold step toward more targeted, efficient, and accessible healthcare solutions [1]. Nanobots are injected directly into the blood stream which act as an internal surveillance system for the human body. Nanobots can detect changes in environmental stimuli and search for molecular assemblies. Nanobots are used by healthcare personnel to examine and monitor patients' health in real time, as well as to record their daily nutritional needs and give medications. In general, nanomedicine is the process of detecting, treating, and preventing disease and traumatic injury, reducing pain, and conserving and improving human health by employing molecular instruments and molecular understanding of the human body [2].

Nanotechnology, dubbed "the manufacturing technology of the twenty-first century," will enable the development of a wide range of economically complicated molecular machines (including, incidentally, molecular computers). Nanomedicine has the potential to develop technology that can function within the human body to diagnose illnesses earlier, as well as locate and measure hazardous substances and cancer cells. When inserted into the body via the intravenous route or cavities, a surgical nanorobot controlled or directed by a human surgeon can function as a semi-autonomous on-site surgeon. It will lead to the development of computer-controlled molecular instruments that are much smaller than human cells yet have the accuracy and precision of medication molecules. For the first time, such instruments will allow medicine to interfere at the cellular and molecular levels in a sophisticated and regulated manner [3].

An integrated computer system could control the functions of the device, including detecting diseases, identifying injuries, and performing repairs through nanomanipulation. Throughout the process, it would maintain communication with the supervising surgeon using encoded ultrasonic signals. What is exciting is that the nanobots replicated by means of an entirely new form of biological reproduction. The team is working on gaining a deeper understanding of the mechanism displayed by this type of nanobot. However, it is expected to be leveraged in regenerative medicine to help treat cancer, traumatic brain injury, birth defects, and more [4].

Although ethical concerns create some uncertainty around the future of xenobots, researchers remain enthusiastic about their potential. These bioengineered organisms could play a significant role in various applications, such as removing microplastics from oceans, collecting toxins and radioactive waste from hazardous environments, enabling more precise and efficient drug delivery, and assisting in the repair of damaged cells and tissues.

**Challenges Faced by Nanobots**

In general, they have contributed significantly to the advancements in nanobot development over the past several years; however, there are a few issues that must be resolved in order to effectively promote these nanobots. The development and deployment of nanobots in healthcare face several challenges. Some obstacles stem from the high costs associated with advanced development, the need for a consistent and reliable power source, and the selection of materials that are chemically non-reactive and biocompatible. On the other hand, efforts are being made to integrate nanobots into medical diagnostics and treatment while ensuring compliance with legal and ethical standards, particularly in safeguarding patient data and ensuring it is securely transmitted to authorized recipients.

Effective data transmission also depends on establishing reliable wireless networks and clearly defining signal strength parameters. Depending on the treatment duration, both biodegradable and non-biodegradable materials are employed—biodegradable materials for short-term use and non-biodegradable for long-term applications. Additionally, the safe retrieval or degradation of nanobots after completing their function is a crucial factor considered during their design and development [5].

**Substructures in a nanobots include**

1. **Payload**: A small dose of drug or medicine is stored in this void section. The nanorobots could travel through the bloodstream and deliver the drug to the infection or injury site.
2. **Micro camera**: A miniature camera could be included in the nanorobot. When manually navigating through the body, the operator can steer the nanorobot.
3. **Electrodes**: Using the electrolytes in the blood, the electrode mounted on the nanorobot could form a battery. These protruding electrodes could also kill the cancer cells by generating an electric current and heating the cancer cells to death.
4. **Lasers**: These lasers could burn harmful material like arterial plaque, blood clots, or cancer cells.
5. **Ultrasonic signal generators**: These generators are used when the nanorobots target and destroy kidney stones.
6. **Swimming tail**: Because nanorobots travel against the blood flow in the body, they will require a means of propulsion to enter the body.

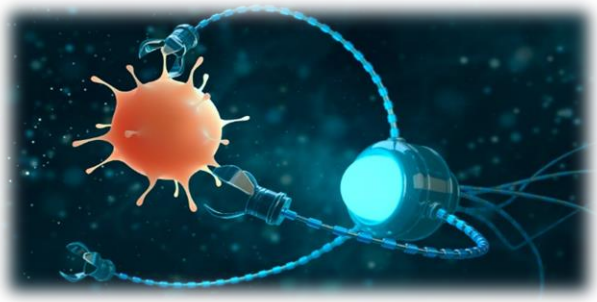

**Figure 1:-** Structure of nanobot

**Types of Nanorobots**

Generally speaking, there are two types of nanobots: military and medicinal. When nanobots cooperate and coordinate during missions, or exhibit collaborative behaviours, the aggregate performance of the nanobots can occasionally yield superior outcomes. Certain nanobots must have the capacity to self-assemble, reproduce like single-celled organisms, and self-heal in the event of harm. Planning and processing of information Particularly significant is the processing of data gathered from the biological environment and nanobot programming. These two kinds of nano-robots are employed in military applications in addition to identification. The most often researched nanorobots are both organic and inorganic. DNA cells from bacteria and viruses are combined to generate organic nanorobots, sometimes referred to as bio-nanorobots. The organism is less harmed by this kind of nanorobot. Inorganic nanobots are more dangerous than organic ones and are made of materials such as synthetic proteins, diamond formations, and other minerals. Researchers have come up with a method to get around this toxicity problem by encasing the robot, which reduces the likelihood that the body's self-defence system will destroy it. Scientists can gain an understanding of how to energise micro and nano-sized devices using reactionary processes if they understand the biological motors of living cells [6]. The Federal Fluminense University's Chemistry Institute

developed a nano valve, which consists of a tank with a shutter over it that contains dye molecules that can exit uniformly when the cover is opened. Made of beta-cyclodextrins, organometallic compounds, and silica (SiO2), this device is also natural and will be used in medicinal settings. In certain research, proteins are used to power nanomotors that can move massive objects. DNA hybridisation and antibody proteins are also used to create nanorobots.

The process by which two complementary single-stranded DNA and/or RNA molecules join forces to generate a double-stranded molecule is known as DNA hybridisation. There are numerous chemical substances that can be used to functionalise a nanorobot. DDS, which acts directly on specific human body cells, has been studied in nanomedicine. Researchers develop tools that can concurrently modify the dosage and volume of release while delivering drugs to specific locations. Joint difficulties, dental issues, diabetes, cancer, hepatitis, and other ailments can be treated with this DDS that uses nanorobots. One advantage of this technology is its capacity to identify and treat diseases with little harm to healthy tissues, reducing the possibility of side effects and directing cellular and subcellular healing and remodelling therapy [7].

**Medical applications of nanorobotic system**

The rapid advancement of molecular robotics is increasingly transforming the healthcare industry, enabling safer and more efficient medical procedures while significantly reducing the risk of human error. Recent progress in DNA nanotechnology has further driven the adoption of nanobots in regenerative medicine, which is anticipated to contribute substantially to the growth of the global nanobot market.

Nanobot technology is being integrated into medical diagnostics and treatment, particularly in the early detection and management of chronic conditions like diabetes. Additionally, the expanding utility of microscopes and other precision instruments is expected to fuel the growth of nanobiotechnology in the coming years. Owing to their minuscule size, nanobots are capable of performing highly intricate tasks quickly and with exceptional precision—far surpassing the efficiency of conventional medical procedures.

In the current healthcare landscape, the increasing workload and stress experienced by medical professionals is a pressing concern. Nanobots offer a promising solution by automating repetitive and specialized tasks, thereby easing the burden on doctors, nurses, and other healthcare personnel.

With ongoing technological advancements, nanorobotic systems are poised to revolutionize several areas of medicine. They hold transformative potential in cancer therapy, diabetes monitoring, wound care, dental procedures, and blood diagnostics. These nanoscale robots are composed of microscopic components, each engineered to perform specific tasks such as sensing, signaling, and processing data at the cellular level.

For instance, in diagnostic applications, nanobots can access regions of the body that traditional nanoparticles cannot reach. In targeted drug delivery, nanobots can transport medication directly to affected areas, enhancing the efficacy of treatment. In severe conditions such as cancer and cardiovascular disease, nanobots are instrumental in identifying diseased cells and delivering precise, localized therapy—thereby improving patient outcomes and minimizing side effects.

**Nanobots in Cancer Diagnosis**

One of the most important tactics in the fight against cancer is early diagnosis. However, existing diagnostic methods have limitations because of the nature of cancer. Techniques that assess different biomarkers, for instance, have been used in recent years as an early diagnosis tool; nevertheless, these techniques are limited because of the new concentrations of these biomarkers in bodily fluids. A path to extremely sensitive and precise early cancer diagnoses is provided by nanotechnology. In order to overcome the shortcomings of the present approaches and enable the early diagnosis of various cancer kinds, scientists have been working on creating a nanobot that can accurately test important cancer biomarkers at low concentration levels [8].

A folding-DNA nanobot that can precisely identify and image tumor-related biomarkers in living cells has been created by recent study. As a biorecognition tool, this nanorobot is made up of two nanoparticles connected by a DNA aptamer. Although still in its infancy, the innovative nanobot holds potential for use in early cancer detection applications.

Because of their autonomous motion and unique biomolecular interaction skills for bio-analysis and diagnostics, nanoscale robots with self-propelling and navigating capabilities have emerged as an intriguing area of research. Here, it presents a magneto-fluorescent nanorobot ("MFN") based on magnesium (Mg)-Fe3O4 that can quickly and selectively separate cancer cells while self-propelling in blood without the need for other additives.

Simple surface modifications and conjugation chemistry were used to construct and create the nanobots, Mg-Fe3O4-GSH-G4-Cy5-Tf and Mg-Fe3O4-GSH-G4-Cy5-Ab, which assemble several components, including EpCAM antibody/transferrin, cyanine 5 NHS (Cy5) dye, fourth generation (G4) dendrimers for multiple conjugation and glutathione (GSH) by chemical conjugation onto one side of Mg nanoparticle [9]. The nanobots moved effectively in blood samples as well as in biological media simulations. The nanobot delivers significant increases in sensitivity, efficiency, and speed by significantly improving the capture of cancer cells. It does this by moving continuously when exposed to water and by using the Fe3O4 shell on the magnesium nanoparticle for magnetic guiding. In

serum and whole blood, the nanobots demonstrated exceptional cancer cell capture efficiency of over 100%, particularly with MCF7 breast cancer cells.

**Nanobots in rescuing from diseases**

Researchers utilized a well-established mouse tumor model, in which human cancer cells are introduced into mice to trigger aggressive tumor formation. Once the tumors began to develop, nanorobots were deployed to intervene. These nanorobots were constructed from flat, rectangular DNA origami sheets, each measuring approximately 90 by 60 nanometers. A critical component of their design was the attachment of thrombin—a blood-clotting enzyme—on their surface. Thrombin works by clotting blood within the vessels that supply nutrients to the tumor, effectively blocking blood flow and inducing the death of tumor tissue, similar to a localized "mini heart attack" within the tumor. To create these nanorobots, an average of four thrombin molecules were first anchored to a flat DNA scaffold. This sheet was then folded into a hollow tube-like structure, resembling a rolled piece of paper. The nanorobots were administered intravenously into the mice, allowing them to circulate through the bloodstream and target the tumor sites. The precision of these nanorobots in targeting cancer cells lies in the inclusion of a DNA aptamer—a specialized molecular payload on their surface. This aptamer was designed to recognize and bind to Nucleolin, a protein found in high concentrations on the surface of tumor endothelial cells but absent on healthy cells. This targeting mechanism ensured that the nanorobots selectively attacked cancerous tissues while sparing normal, healthy cells [10].

**Working procedure of a nanorobot**

In the modern era, numerous advanced fabrication methods have been applied to the development of classical nanorobots. Techniques such as electrochemical deposition, physical vapor deposition, strain engineering of nano-microtubes, and direct laser writing have played key roles in their production. However, the growing demand for biocompatibility and precise control has led to the emergence of microfluidic technologies for synthesizing micro- and nanorobots.

Microfluidics involves the manipulation of small fluid volumes within microscale channels to create functional devices. Compared to traditional fabrication methods, this approach offers several advantages, including enhanced biocompatibility, the ability to integrate complex structures, and precise control over chemical composition—making it highly suitable for biomedical applications.

Nanorobotics function by using Nanorobots—also referred to as nanoscale robots—are used in nanorobotics. Nanorobots' functionality and design can differ based on: nanoscale robots, sometimes referred to as nanorobots. Nanorobots' functionality and design can differ based on:

Nanorobots' sensors could identify particular signals or circumstances, such as the presence of a particular kind of substance or molecule, and then relay this data to the control system. This data might then be used by the control system to determine what the nanorobot should do.

The actuators of the nanorobots could be used for a variety of tasks, such as movement, drug release within the human body, and material and structural manipulation.

Nanorobots must be able to navigate and interact with their surroundings in order to carry out their intended duties. Numerous techniques, such as self-propulsion, remote control, or chemical or biological mechanisms, can be used to achieve this.

**Cancer detection and diagnosis**

Because early cancer detection can significantly improve patient survival rates, it is critically important. Research on tumor-killing nanorobots continues to advance, and as nanorobot designs become more sophisticated, early-stage clinical cancer diagnosis becomes more precise and efficient. Using positron emission topography, Maheswari ET. AL. presented an additional tumor-detecting nanorobot that could investigate the growth of tumour cells in vivo.

To enable the nanorobot to be controlled via pre-programmed processes on the Arduino software platform, an embedded system was installed in the interim. The nanorobot was constructed using an isotope-labeled nano-carbon material to prevent any possible negative effects on the human body. Because of their dependable stability and safety, nanorobots won't injure a human after being put into their body.

The nanorobot will be expelled from the human body as waste after completing the predetermined activities. The nanorobot is made up of a sensor, a power source, and a camera, just like a macro-robot. Furthermore, sophisticated algorithms were used to determine the quickest path, and the integrated sensor aids in the nanorobot's obstacle avoidance.

On the surface of cancer cells, overexpressed biomarkers make excellent targets for biomedical engineering, treatment, and disease diagnosis. A 3D DNA nanorobot was created and manufactured by Peng et al. With bispecific recognition, this 3D DNA-based logic gate nanomachine was created to target overexpressed cancer cell biomarkers. Additionally, the DNA nanorobot has a great deal of therapeutic promise for application in the clinical treatment of tumours and can execute Boolean logic operations on the cancer cell membrane [11].

Under the driving force, scientist created a nanorobot that could identify cancer cells in the blood and deliver the medication to the tumour location. This nanorobot had the capacity to harvest blood energy and store electricity in an integrated capacitor. Generally speaking, cancer cells have higher glucose levels than healthy cells.

A high glucose level can encourage the growth and spread of cancer cells. In order to identify cancer cells by detecting the increased amount of glucose-driven electric current in cancer cells, a glucose sensor was immobilised to a CNT-based nanorobot. At the same time, this method might allow the electric current to activate a nanoelectromechanical (NEM) relay (mechanical transistor), which would break the chamber ceiling and reveal a medication that the immune system has designated for cell eradication. This concept is in line with the effort on designing an autonomous computational nanorobot for in vivo medical diagnosis and treatment.

Natural Killer (NK) cells are a type of lymphocyte that play a crucial role in the body's innate immune defense. Notably, they possess the ability to cross the blood-brain barrier (BBB), enabling them to participate in immune responses within the central nervous system.

As previously reported, NK cells were employed in cancer immunotherapy. By encasing the NK cell membrane on an AIE-active polymeric nano endoskeleton, Deng et al. created NK cell-mimic nanorobots with aggregation-induced emission (AIE) characteristics.

When photo-excited, the nanorobots may produce intense fluorescence in the NIR-II area and are biocompatible. Additionally, by unzipping tight junction structures, they might self-helpfully penetrate the brain-blood boundaries and concentrate at brain tumour sites in the intricate brain matrix, allowing for high contrast tumour imaging and skull penetration.

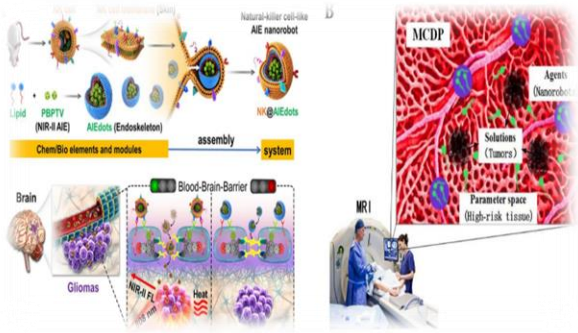


**Figure 2:** Advances in medical nanobots for future cancer treatment

**Application of nano robots in cancer treatment**

An early diagnosis will increase the patient's chances of receiving cancer treatment. Early on in the development of cancer, tumour cells are detected by nanorobots equipped with chemical biosensors, or nano sensors. The existence of cancerous cells within the body will be detected by this nano sensor. The majority of anticancer medications have a narrow therapeutic index, which can lead to gastrointestinal problems, haematological side effects, and toxicity to healthy stem cells, among other things. The primary characteristic of neoplastic cells is their fast division, which is destroyed by conventional chemotherapeutic drugs. The majority of anti-cancer medications, such as doxorubicin, are used to treat a variety of cancers, including Hodgkin's disease (HD), when treatment is given in conjunction with other antineoplastic agents to lessen their toxicity.

Nanorobots, functioning as devices that circulate through the bloodstream, offer valuable support in key aspects of cancer treatment. When equipped with chemical biosensors, these nanoscale tools can detect cancer cells at an early stage within the body, significantly improving the chances of timely diagnosis and intervention.

For this purpose, integrated nano sensors can be used to determine the strength of Cadherin signals. Therefore, for the use of nanorobots in cancer therapy, a hardware architecture based on nano bioelectronics is developed. Researchers have genetically modified *Salmonella* bacteria to respond to chemical signals emitted by cancer cells, guiding them directly to tumor sites. Once at the tumor, these bacteria—each carrying tiny robotic components about three micrometres in size—automatically release drug-loaded capsules. This innovative nanorobot system, referred to as a "bacteriobot," delivers medication precisely to the tumor, effectively targeting cancerous cells while minimizing damage to healthy tissues. As a result, this approach helps avoid many of the harmful side effects commonly associated with traditional chemotherapy.

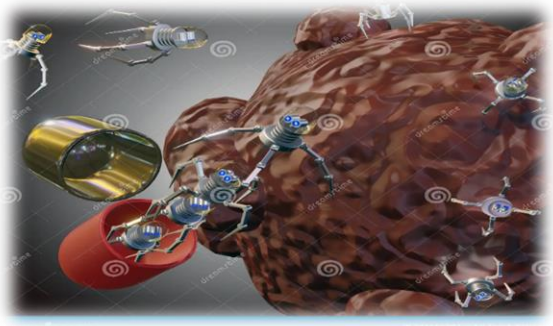

**Figure 3:** Nanorobots targeting tumor site.

**Breast Cancer Nano-Theranostics (BC):**

Nanorobots are engineered to perform highly specialized functions at microscopic scales, even down to the molecular or organelle level. In the context of breast cancer, these advanced nanodevices offer promising solutions to several critical challenges. These include the heterogeneity of breast cancer, the limitations of non-specific drug delivery, the invasiveness of conventional diagnostic and surgical procedures, resistance to standard cancer therapies, and the need for real-time tumor tracking. By addressing these complexities, nanorobots play a vital role in enhancing the precision and effectiveness of breast cancer theranostics.

**Microrobots for long-range cancer targeting**

The effectiveness of microrobots in cancer treatment largely depends on the tumor's location and the most

suitable delivery route. Tumors located in the gastrointestinal or reproductive systems can often be accessed through oral, rectal, or vaginal administration, which allows for more flexibility in microrobot size and design. These localized delivery routes typically involve fewer constraints compared to other methods.

On the other hand, **systemic administration** is particularly advantageous for targeting a wide range of solid tumors across the body, as well as blood-related cancers and circulating metastatic cells. This method enables microrobots to travel through the bloodstream, providing broader therapeutic reach and potential for treating multiple tumor sites simultaneously. To a certain degree, systemically circulating microrobots will share traits with nanoparticles, such as the ones mentioned above, which will enable them to evade biological filters and spread. In this regard, it is notable that fabrication methods can be limited to certain size regimes. Only lately, for instance, have bottom-up self-assembled synthetic microrobots been expanded to tiny, sub-micrometer regimes that are best suited for systemic use.

It's exciting to see that the first in vivo results for synthetic microrobots smaller than a micrometre are showing that their motion can significantly increase extravasation into tumour tissues. By avoiding biological filters like the lung, liver, spleen, and kidney, other administration routes—such as through the reproductive system or the gastrointestinal tract—allow for the targeting of specific tumours or cancer lesions inside these systems without the need for systemic circulation. The precise interactions between microrobot motility, size, shape, and composition that impact the half-life, biodistribution, and long-range cancer targeting efficiency of various microrobot types in vivo will be clarified by future systematic research. In order to access sick tissue, NPs can also be designed to change form in response to biological substances. DNA strands are affixed to tiny pieces of metal that make up these shape-shifters. Modular NPs are used in the targeted molecular delivery system, and the presence of particular DNA sequences can change their size, shape, and chemistry. Until a DNA strand attaches itself to a DNA sequence that is recognised as a cancer marker, the NPs remain innocuous in the bloodstream. Following this, the particle undergoes a shape change before performing its intended job, which is to target the cancer cells, expose a medication molecule to the diseased cell, and tag the cancerous cells with a signal molecule. Theoretically, this method might be used into customised nanomedicine treatments, further customising the particles to deliver medications just to designated tumours [12].

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Research Article

# Density Functional Theory based investigation of Structural, Electronics and Magnetic Properties of Rare Rarth (Er) doped ZnGa Compound

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*

**Abstract**

The electronic and magnetic properties of the intermetallic compound ErZnGa were investigated using density functional theory (DFT). This chemical crystallizes in a hexagonal $CaIn_2$-type structure and is a member of the space group $P6_3/mmc$ (No. 194). Parameters of Structure: The anticipated lattice constants ($a_0$, $c_0$), bulk modulus ($B_0$), and its first-order pressure derivative ($B_0'$) demonstrate significant agreement with empirical and previously documented theoretical values, hence confirming the accuracy of the used computational method. The electrons localised in the 4f orbitals of erbium (Er) are crucial in determining the magnetic response of ErZnGa and significantly influence its magnetic properties. Electronic qualities: The density of states (DOS) and band structure of the molecule were thoroughly examined in order to assess its electronic qualities. Understanding these properties is necessary to evaluate the material's potential use in electrical and magnetic devices. The findings derived from calculations align with the existing experimental and theoretical data, demonstrating the dependability of the used approaches. All things considered, this study contributes to our understanding of the interplay between ErZnGa's electrical and magnetic properties, paving the way for more research into its possible technological applications.

**Keyword:** Structural properties; intermetallic materials; Density Functional Theory.

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## Introduction

RTX-type trivalent rare-earth intermetallic compounds exhibit a wide array of intricate mechanical, chemical, and physical characteristics. In this context, R denotes a rare-earth element, T signifies a transition metal, and X symbolises a p-block element. Almost 2000 different combinations of RTX-type compounds have been identified and studied [1]. These materials provide a variety of options for research and education, which makes them significant to materials science. Consistent with this research direction, the binary compound $ErCu_2$ was altered to produce the ternary intermetallic compound ErCuGa, which crystallises in the $KHg_2$-type structure inside the space group Imma [2–5]. A new ternary compound called ErCuGa is produced by partially replacing Cu atoms with Ga atoms in a 1:1 ratio [6]. By focusing our study on ErZnGa, a ternary compound that has structural and chemical characteristics with ErCuGa, we have expanded on this foundation. However, there is presently no comprehensive literature on the electrical and magnetic properties of ErZnGa. Despite its structural similarity to ErCuGa, nothing is known about the fundamental physical properties of ErZnGa. The crystallographic properties were analysed using X-ray powder diffraction, revealing that the compound crystallises in a $CaIn_2$-type hexagonal structure within the space group $P6_3/mmc$ [7–8]. The main objective of this study is to theoretically analyse the electronic and magnetic properties of the ErZnGa compound, including an exploration of its band structure, total and partial density of states (DOS), and magnetic moment. We used density functional theory (DFT) with full-potential augmented plane wave and localised orbital (FP-LAPW+lo) techniques [9].

## Computational Approach

The calculations were performed using the WIEN2k software, which use the linear augmented plane wave (LAPW) method extensively [10]. To ensure accurate convergence of the energy eigenvalues, the basis set was expanded under the condition RMT × Kmax = 7, where RMT represents the minimum muffin-tin radius of the atomic spheres inside the unit cell, and Kmax indicates the maximum vector magnitude for the plane wave expansion. The valence wave functions of the atomic spheres were expanded to a maximum angular momentum quantum number of lmax = 10. The Fourier expansion of the charge density was performed up to the reciprocal lattice vector Gmax = 12. The tetrahedron method was used for Brillouin zone integration using a dense k-point mesh of 1000 points, yielding a high level of accuracy in the electronic structure simulation. Muffin-tin radii ($R_{MT}$) of 2.00, 2.43, and 2.43 bohr were used for Er, Zn, and Ga, respectively, and were found to be suitable for producing reliable results. The computed Fermi energy of the system was 0.4307 eV, as shown in Table 1. In connection with its magnetic characteristics, the material's magnetic moment was

also calculated. By implying their use in spintronic devices, these magnetic properties indicate a promising path for the advancement of state-of-the-art spin-based electronic technologies.

**Result:**

**Structure Properties**

The structural features of the ErZnGa compound have been obtained by experimental lattice parameter optimization. According to the most current report, the molecule has crystallized in the cubic B1-phase, in the space group P63/mmc, with a0 = 4.393 and c0 = 7.048 Å [7]. For Er, Zn, and Ga, their corresponding atomic positions are 2a (0, 0, 0), 2b (0.33, 0.66, 0.71), and 2c (0.33, 0.66, 0.28) [7]. The ErZnGa compound's crystal structure was obtained using the xcrysden program, as shown in figure 1. A software program called Xcrysden was created to visualize crystalline and molecular structures. In addition to allowing interactive manipulation via rotation and other methods, it permits the overlay of structures. The GNU/Linux operating system powers the program. Birch-Murnaghan's equation of state has been used to calculate geometry and structural parameters, as has been explained in references [11–12]. Correlation between the system's total energy and the unit cell's volume is part of the technique. Figure 2 shows the stable structure of the minimal ground state energy in the ferromagnetic phase. Through the integration of both theoretical and experimental data, the lattice constant was optimized. Table 1 presents the computed ground state parameters, including bulk modulus ($B_0$), lattice constant ($a_0$), pressure derivative of bulk modulus, and total energy.

**Table 1**

Lattice parameters, $a_0$, $c_0$ (Å), Bulk modulus, $B_0$ (GPa), Pressure derivative of bulk modulus, $B_0'$ (GPa) equilibrium condition (at 0K), Fermi energy ($E_F$ in eV).

| Compounds | $a_0$ | $c_o$ | Bo | $B_0'$ | $E_F$ |
|---|---|---|---|---|---|
| ErZnGa | 4.573 | 7.206 | 71.2734 | 1.5519 | 0.4307 |
| Exp. - | 4.393[7] | 7.048[7] | ---------- | ----- | --------- |

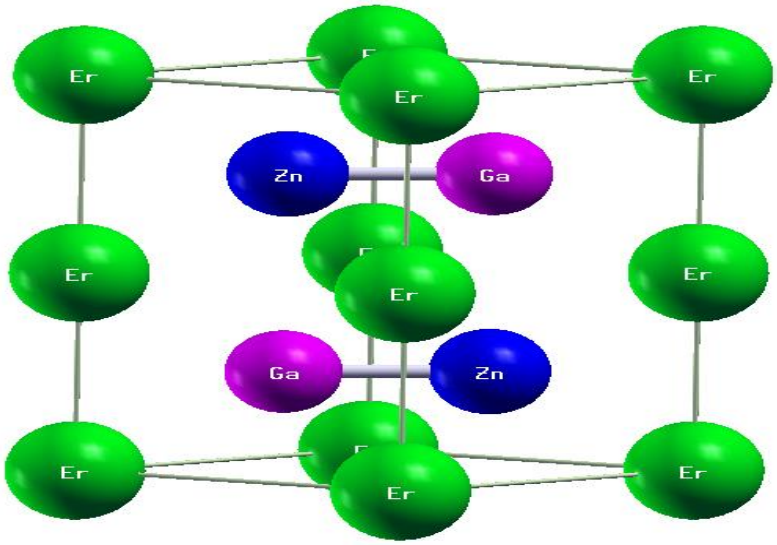


Figure-1 Unit cell structure of ErZnGa

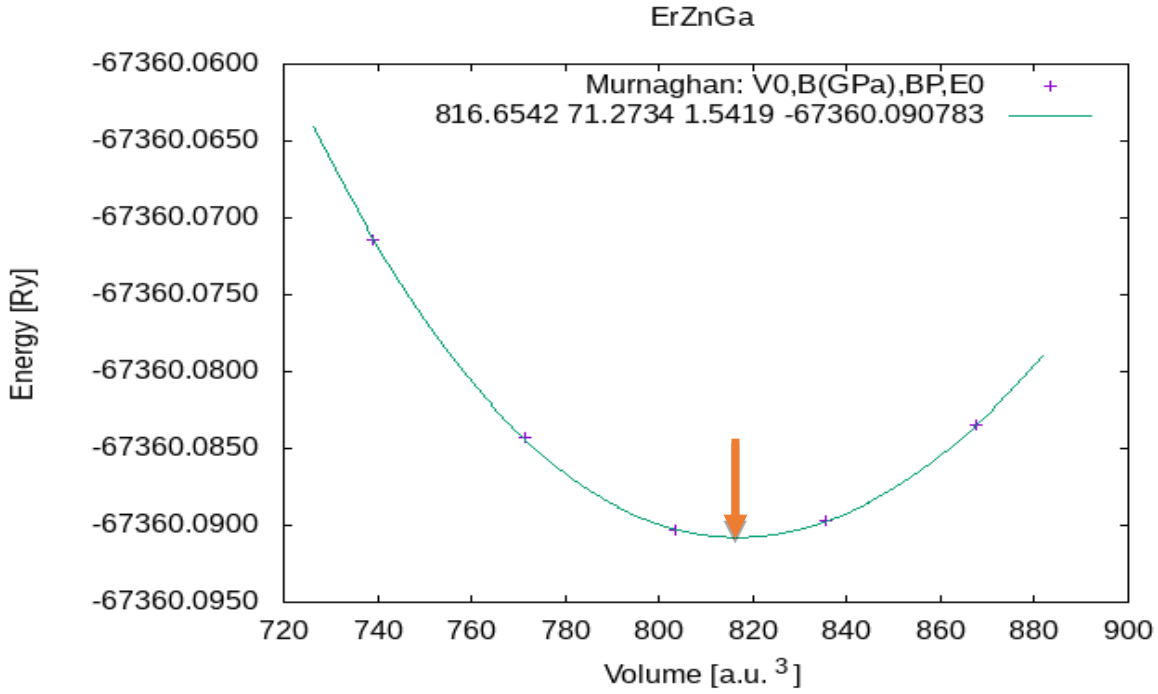


**Figure-2 Energy Vs. volume curve with using murnaghan equation of state.**

**Electronic and Magnetic Properties**

The spin-resolved band structure and density of states have been graphed, and the electronic characteristics have been computed using the GGA method. Using the GGA approach, the band structure and density of states have been visually shown using the lattice constant that was determined using GGA calculation. These diagrams usually provide a good grasp of a substance's electrical properties. To understand the obtained results, the GGA approach was used to create band structure plots, which are shown in figure 3, and density of state plots, which are shown in figure 4. The origin is thought to be the location of the Fermi level. The band profiles support these compounds' metallic characteristics by demonstrating a strong overlap between the valence and conduction bands (shown in figure 3) and the absence of a band gap at the Fermi level.

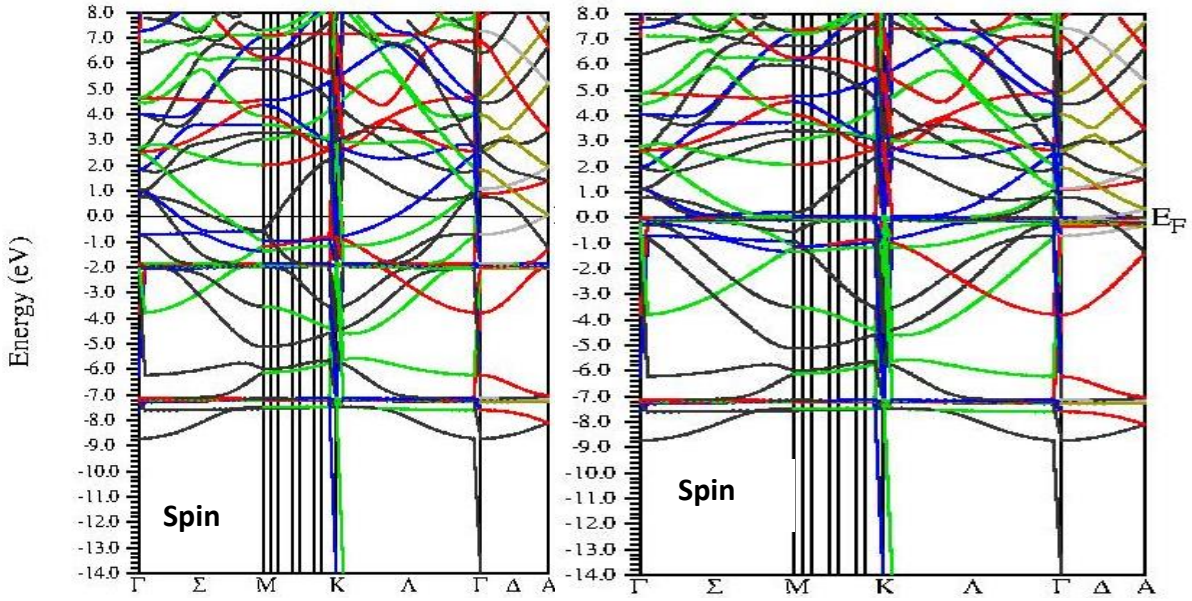


Figure-3

This work established the equilibrium lattice constant and total density of the ErZnGa compound using the GGA technique. The states linked to the 'f' orbitals of erbium exhibit a little displacement; yet, the band structures demonstrate significant similarities between the two spin states. The Zn-d states comprise the lowest energy band, ranging from about -8.0 eV to -3.0 eV. The flat band located in the conduction band at the Fermi level mostly results from the existence of erbium's 'f' states. The examination of the band structure indicates that the ErZnGa combination has a predominant metallic character due to the existence of Zn-d and Ga-s states at the Fermi level. The cumulative magnetic moment determined for this chemical is shown in Table 2. The density of states (DOS) at the Fermi level (EF) for the aforementioned molecule was computed using the GGA technique under ambient circumstances, revealing a value of 0.4307 for both majority and minority spin states.

**Table 2**

Calculated spin magnetic moments ($\mu_B$) of ErZnGa using PBE-GGA.

| | ErZnGa |
|---|---|
| Interstitial region | -0.13968 |
| Er | 2.43466 |
| Zn | -0.00757 |
| Ga | 0.00240 |
| Total | 4.71929 |

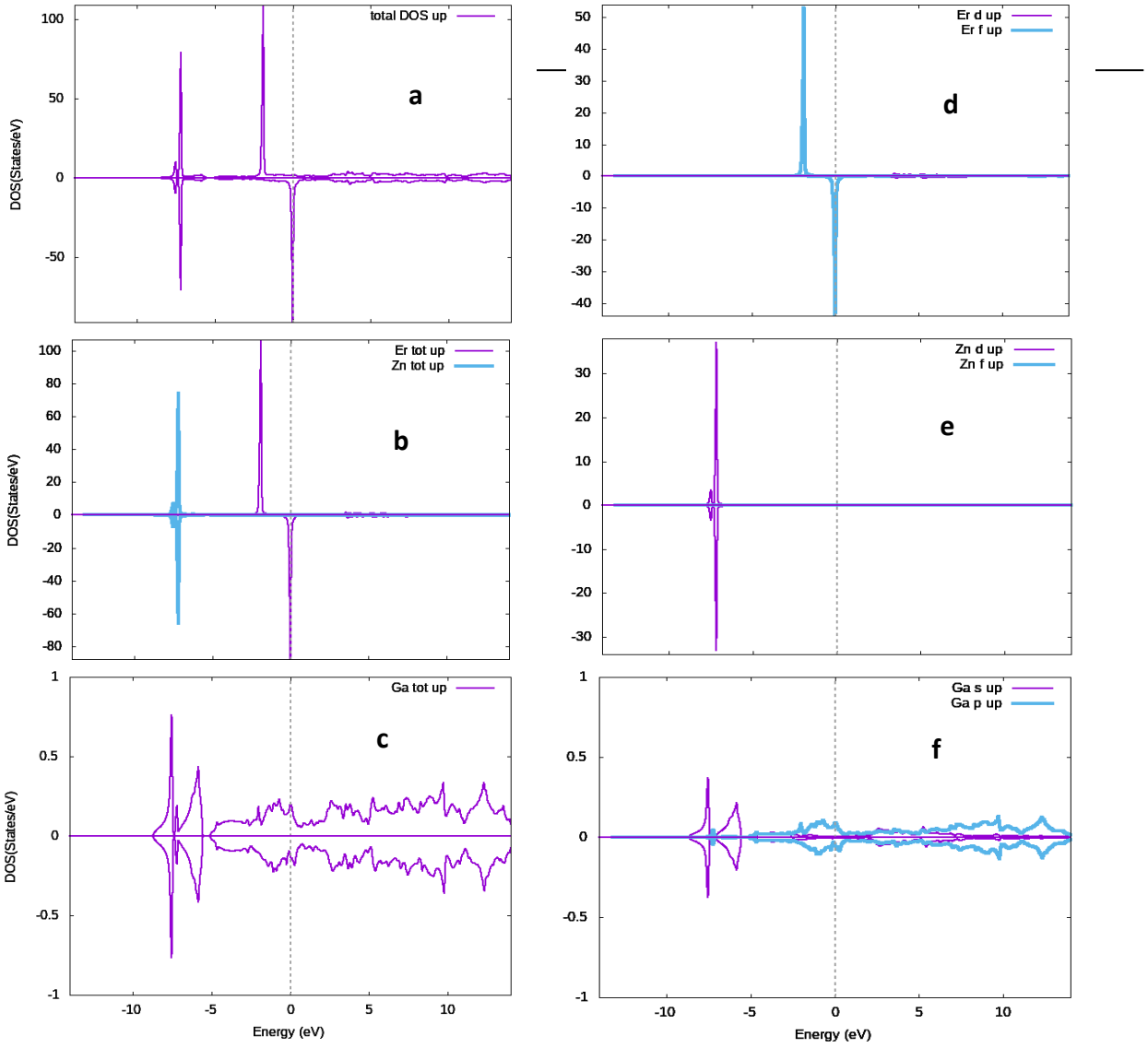


Figure-4 shown that DOS and PDOS are following (a) Total DOS for ErZnGa, (b) Er total and Zn total DOS, (c) Ga total DOS, (d) Er-d and Er-f PDOS, (e) Zn-d and Zn-f PDOS, and (f) Ga-s and Ga-p PDOS

**Conclusion**

In the present work, the FP-LAPW approach is used to thoroughly analyze the electrical and structural features of ErZnGa in the framework of density functional theory. The PBE-GGA technique is used to approximate the correlated energy exchange. Good agreement with experimental data is shown by the structure characteristics. The material exhibits no band gap, according to the band structures of these compounds. This indicates that the density of state and metallic character of the ErZnGa compound are confirmed by this compound. Er-element-based magnetic compound confirmation is known as a magnetic property.

**Source of Support: Nil**
**Conflict of interest: Nil**
**Acknowledgement:**

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