Trends in Immunotherapy 2024, 8(2), 8970.
https://doi.org/10.24294/ti8970

Review

Advancements in the treatment of autoimmune diseases: Integrating artificial intelligence for personalized medicine

Mohd Afzal[1], Ashok Kumar Sah[2,*], Shagun Agarwal[3], Akifa Tanzeel[4], Rabab H. Elshaikh[2], Fawzia Abdalla Alobeidli[5], Ayman Hussein Alfeel[5], Ranjay Kumar Choudhary[6], Ajabsingh Choudhary[7]

[1] Department of Medical Laboratory Technology, Arogyam Institute of Paramedical & Allied Sciences (Affiliated to H.N.B.Uttarakhand Medical Education University), Roorkee 247661, Uttarakhand, India
[2] Department of Medical Laboratory Sciences, College of Applied & Health Sciences, A' Sharqiyah University, Ibra 400, Oman
[3] School of Allied Health Sciences, Galgotias University, Yamuna express way, Greater Noida 203201, Uttar Pradesh, India
[4] Bushra Clinic ENT & Children's, Khan Estates, Redhills, Hyderabad, Telangana 500004, India
[5] Department Medical Laboratory Sciences, College of Health Sciences, Gulf Medical University, Ajman 4184, United Arab Emirates
[6] Department of Medical Laboratory Technology, Amity Medical School, Amity University Haryana, Gurugram, HR 122412, India
[7] Department of Medical Laboratory Technology, School of Allied Health Sciences, Noida International University, Greater Noida, Uttar Pradesh 203201, India
*** Corresponding author:** Asok Kumar Sah, ashok.sah8@gmail.com

CITATION

Afzal M, Sah AK, Agarwal S, et al. Advancements in the treatment of autoimmune diseases: Integrating artificial intelligence for personalized medicine. Trends in Immunotherapy. 2024; 8(2): 8970. https://doi.org/10.24294/ti8970

ARTICLE INFO

Received: 3 September 2024
Accepted: 21 October 2024
Available online: 11 November 2024

Abstract: The incorporation of artificial intelligence (AI) into medical practice has considerably improved the treatment of autoimmune disorders, opening new avenues for personalized therapy. This study examines advances in AI-driven therapeutic options for autoimmune illnesses, including both current and developing treatments. Traditional therapies for autoimmune illnesses, such as immunosuppressive therapy and biologics, attempt to alleviate symptoms but frequently fall short of offering personalized care. Emerging approaches, such as precision medicine and artificial intelligence, are altering the landscape by harnessing massive volumes of patient data to better customize therapies. AI holds the ability to transform autoimmune disease therapy by enhancing diagnosis, discovering biomarkers, optimizing drug development, and personalized treatment procedures. Real-world applications and case studies are examined to demonstrate how machine learning algorithms have improved treatment tactics for rheumatoid arthritis, systemic lupus erythematosus, and multiple sclerosis. While AI has many advantages, like enhanced diagnosis accuracy and personalized therapy, it also has drawbacks, such as data privacy, the requirement for vast datasets, algorithmic bias, and a lack of explain ability. This study emphasizes the advantages of AI, such as improved patient stratification and predictive modelling, while also discussing its drawbacks, such as ethical problems and the possibility of data exploitation. AI presents intriguing prospects for treating autoimmune diseases, but more research and cooperation are required to overcome current difficulties and completely integrate AI into clinical practice.

Keywords: autoimmune diseases; artificial intelligence; precision medicine; genomics

1. Introduction

Autoimmune diseases, initially identified by Ian Mackay and Macfarlane Burnet, are marked by the body's inability to recognize its own cells and tissues as "self," leading to an inappropriate immune response involving lymphocytes and/or antibodies [1]. Specific criteria have been devised to define a condition as autoimmune [2]. Autoimmune diseases encompass a broad spectrum of disorders wherein the body's immune system erroneously targets and attacks its own tissues, perceiving them as foreign invaders. This immune system dysfunction leads to inflammation and damage to various body parts, manifesting in a variety of symptoms and complications [3]. Autoimmune diseases can affect almost any part of the body, including the skin, joints, organs, and glands. Some of the most common autoimmune diseases include rheumatoid arthritis (RA), systemic lupus erythematosus (SLE), multiple sclerosis (MS), and type 1 diabetes mellitus (T1DM). Each disease has its unique pathophysiology, symptoms, and treatment approaches, but they share a common underlying mechanism: an aberrant immune response [4,5]. Autoimmune diseases collectively affect millions of people worldwide, with a higher prevalence in women than in men. The exact cause of autoimmune diseases remains unclear, but it is believed to involve a combination of genetic, environmental, and hormonal factors [6]. The pathogenesis of autoimmune diseases involves complex interactions between genetic predisposition and environmental triggers. These triggers may include infections, exposure to certain chemicals, and other external factors that can initiate or exacerbate the immune response against the body's tissues. The resulting inflammation and tissue damage can lead to chronic disease and disability [7].

In recent years, artificial intelligence (AI) has become more important in the diagnosis, management, and therapy of autoimmune disorders. AI-enabled technologies, such as machine learning (ML) and deep learning, have the potential to transform how these diseases are studied and treated. AI can evaluate massive volumes of patient data to find patterns and forecast illness development more accurately than traditional approaches [8]. AI algorithms can help find previously unknown biomarkers and therapeutic targets by analyzing genetic, proteomic, and clinical data, opening the door for personalized medicine. Personalized medicine seeks to adapt medicines based on an individual's unique genetic composition and illness features, with the goal of enhancing treatment results and lowering side effects [9].

AI can help in drug discovery by predicting which compounds are most likely to interact well with immune targets, accelerating the development of new treatments. AI-based models can also improve existing treatment procedures by analyzing patient reactions to various medicines, allowing for more accurate modifications and eliminating trial-and-error methods. The integration of AI in autoimmune disease therapy has the potential to make personalized medicine a reality, boosting both diagnosis accuracy and treatment efficacy [10].

The diagnosis of autoimmune diseases often involves a combination of clinical evaluation, laboratory tests, imaging studies, and sometimes biopsies. Treatment aims to reduce immune system activity and manage symptoms. Common treatment strategies include immunosuppressive drugs, biologics, and lifestyle modifications. Emerging therapies, such as stem cell therapy and gene therapy, are also being explored.

The aim of this review is to explore how integrating artificial intelligence (AI) into the treatment of autoimmune diseases enhances personalized medicine, improves patient outcomes, and identifies the associated challenges. It also discusses future research directions and the ethical and regulatory considerations essential for successful AI implementation.

1.1. Prevalence and impact of common autoimmune diseases

Autoimmune disorders affect a large proportion of the world's population, having a considerable influence on world health systems. Common autoimmune diseases are presented in **Table 1**, along with their prevalence and major health impacts:

RA is a chronic inflammatory condition that mostly affects the joints. It affects around 0.5%–1% of the worldwide population. Women are disproportionately afflicted by RA, with rates 2–3 times higher than males. If not treated properly, the illness causes significant joint pain, stiffness, swelling, and even joint destruction. Furthermore, RA patients are more likely to develop cardiovascular illness as a result of systemic inflammation [11,12].

SLE is another common autoimmune illness, with an estimated frequency of 20 to 150 cases per 100,000 persons. SLE mostly affects women, with a female-to-male ratio of around 9:1. This condition can affect several organ systems, resulting in a variety of symptoms such as skin rashes, joint discomfort, renal impairment, and neurological issues. The widespread influence on various organ systems can drastically reduce quality of life and raise death rates among affected people [13,14].

MS is a neurological autoimmune disease that affects over 2.5 million individuals worldwide. Women are almost twice as likely as males to have MS. The condition presents a variety of neurological symptoms, including tiredness, movement difficulty, visual impairments, and cognitive impairment. These symptoms can range in intensity and may result in major impairment over time, significantly affecting patients' everyday life [15,16].

T1DM is an autoimmune disease that destroys insulin-producing beta cells in the pancreas. T1DM affects around one out of every 300 people by the age of 18. There is a modest gender difference, with men more impacted in early infancy and females in adolescence. T1DM needs lifetime insulin medication, blood sugar monitoring, and dietary changes. Patients are more likely to develop cardiovascular problems, which have a substantial influence on their everyday lives and long-term health [17,18].

Table 1. Prevalence and impact of common autoimmune diseases.

Autoimmune disease	Prevalence	Gender disparity	Major health impacts	Ref.
Rheumatoid Arthritis (RA)	0.5%–1% of global population	Women are 2–3 times more affected than men	Joint pain, stiffness, swelling, potential joint destruction, increased cardiovascular risk	[11,12]
Systemic Lupus Erythematosus (SLE)	20–150 cases per 100,000 people	Female-to-male ratio of about 9:1	Multisystem involvement, skin rashes, joint pain, kidney damage, neurological complications	[13,14]
Multiple Sclerosis (MS)	2.5 million people globally	Female-to-male ratio of approximately 2:1	Neurological symptoms such as fatigue, mobility issues, vision problems, cognitive impairment	[15,16]
Type 1 Diabetes Mellitus (T1DM)	1 in 300 people by age 18	Slightly higher in males during early childhood and in females during adolescence	Lifelong insulin therapy, blood sugar monitoring, dietary management, cardiovascular disease risk	[17,18]
Sjögren syndrome	Affects 0.1%–4% of the general population.	Predominantly affects women (about 90% of cases).	Causes dry mouth, dry eyes, fatigue, and can lead to complications like lung and kidney damage	[17,19]
Dermatomyositis	Rare, with an estimated 1 in 100,000 individuals.	More common in women, particularly in middle age.	Muscle weakness, skin rashes, and increased risk of malignancy	[20,21]

Table 1. (*Continued*).

Autoimmune disease	Prevalence	Gender disparity	Major health impacts	Ref.
Myasthenia gravis	Affects 20 per 100,000 people.	Early-onset is more common in women; later-onset affects men more.	Causes muscle weakness and can affect breathing and swallowing, requiring medical management.	[22]
Hashimoto Thyroiditis	Common in about 5% of the population.	Primarily affects women, with a female-to-male ratio of about 10:1.	Hypothyroidism leading to fatigue, weight gain, and depression.	[23]
Psoriasis	Around 2%–4% of the global population.	Affects men and women almost equally.	Skin lesions, joint pain (psoriatic arthritis), and a higher risk of cardiovascular disease.	[24]
Graves' disease	Affects about 0.5%–1% of the population.	More common in women, with a ratio of about 7:1.	Hyperthyroidism leading to weight loss, heart palpitations, and eye disease.	[25]
Celiac disease	Affects 1 in 100 people globally.	Slightly more common in women.	Malabsorption of nutrients, digestive issues, and increased risk of certain cancers	[26]
Addison's disease	Rare, affecting 1 in 100,000 people.	Affects both genders equally.	Fatigue, low blood pressure, and severe adrenal insufficiency.	[27]
Scleroderma	Affects 1 in 10,000 to 1 in 100,000 people.	More common in women, especially in childbearing years.	Skin thickening, joint pain, and potential lung, heart, or kidney involvement.	[28]
Reactive arthritis	Occurs in 30–40 per 100,000 individuals, especially after infections.	More common in men	Joint pain, inflammation, and urinary tract symptoms.	[29]

2. Current treatment methods of autoimmune diseases

Table 2 summarizes current treatment methods for autoimmune diseases

2.1. Pharmacological therapies

Corticosteroids: Corticosteroids are a class of steroid hormones that are widely used in the treatment of autoimmune diseases due to their potent anti-inflammatory and immunosuppressive properties. They are effective in reducing inflammation and modulating immune responses, providing symptomatic relief and controlling disease progression in many autoimmune conditions [30]. Corticosteroids function by dampening the immune system, reducing inflammation and decreasing the activity and volume of the immune system's reaction, so lessening the consequences. Furthermore, corticosteroids limit the synthesis of inflammatory cytokines and other mediators of inflammation, which contributes to their effective anti-inflammatory effects [31]. Prednisone, a common corticosteroid used to treat autoimmune illnesses, is frequently given due to its efficiency and adaptability. Methylprednisolone is another commonly used corticosteroid, recognised for its strength and ability to relieve inflammation quickly. Dexamethasone is also commonly used, particularly in situations needing substantial anti-inflammatory treatment due to its long-term effects [32].

Immunosuppressants: Immunosuppressants, such as methotrexate and azathioprine, are widely used in the treatment of autoimmune illnesses to suppress the immune response and avoid tissue damage [33]. These drugs help reduce disease activity, but come with dangers, such as increased infection susceptibility [34].

Biologics: Biologics, such as tumor necrosis factors (TNF) and interleukin-6 (IL-6) inhibitors, are cutting-edge medicines for autoimmune illnesses that target immune system components to decrease inflammation and slow disease development. These medicines are frequently beneficial to people who do not react to conventional treatments and have fewer adverse effects [35,36].

2.2. Non-pharmacological therapies

Physical Therapy: Physical therapy is an important non-pharmacological treatment for autoimmune illnesses. It aims to improve mobility, alleviate discomfort, and avoid joint deterioration with specific exercises and activities [37,38]. This method can dramatically enhance functional skills and quality of life in people suffering from rheumatoid arthritis and lupus.

Dietary modifications: Dietary changes can help manage autoimmune illnesses by lowering inflammation and improving general health. Specific dietary methods, such as the anti-inflammatory diet and gluten-free diet for coeliac disease, have been found to be effective in lowering disease activity and alleviating symptoms [39,40]. These dietary adjustments can help patients better manage their diseases, perhaps lowering prescription use and enhancing quality of life.

Lifestyle Changes: Lifestyle modifications are an important part of managing autoimmune disorders, with an emphasis on adopting good behaviors to enhance general health and prevent illness flare-ups. Regular exercise improves joint function and lowers inflammation, whilst stress management practices like yoga and meditation can reduce stress levels, which are known to aggravate autoimmune disorders. Furthermore, smoking cessation is essential since smoking has been related to increased disease severity in illnesses such as rheumatoid arthritis. Adequate sleep is also necessary for immune system balance and general well-being [41,42].

Table 2. Current treatment methods for autoimmune diseases.

Treatment method	Subcategory	Overview	Major health impacts/benefits	Ref.
Pharmacological therapies	Corticosteroids	Drugs that mimic adrenal hormones, suppressing inflammation and immune response. Common drugs: Prednisone, Hydrocortisone.	Rapid symptom relief, control of disease activity. Risks: Osteoporosis, hypertension, diabetes, weight gain, infection risk.	[30–32]
	Immunosuppressants	Medications that inhibit or prevent activity of the immune system. Common drugs: Methotrexate, Azathioprine, Cyclosporine.	Prevents the immune system from attacking own tissues. Risks: Increased infection risk, liver and kidney damage, nausea, vomiting.	[33,34]
	Biologics	Engineered proteins that target specific components of the immune system. Common drugs: TNF inhibitors, IL-6 inhibitors, B-cell inhibitors.	Targeted therapy with fewer side effects, effective in patients not responding to other treatments. Risks: Injection site reactions, infections.	[35,36]
Non-pharmacological therapies	Physical therapy	Exercises and activities designed to improve movement, strength, and function.	Enhances mobility, reduces pain, prevents joint damage.	[37,38]
	Dietary modifications	Adjustments in diet to manage symptoms and improve overall health. Common strategies: Anti-inflammatory diet, gluten-free diet for celiac disease.	Reduced inflammation, better symptom control, improved gut health.	[39,40]
	Lifestyle changes	Incorporating healthy habits like regular exercise, stress management, smoking cessation, and adequate sleep.	Overall improvement in health, reduced flare-ups, better quality of life.	[41,42]

3. Emerging treatment approaches for autoimmune diseases

3.1. Targeted therapies

Monoclonal Antibodies: Monoclonal antibodies (mAbs) are a potential targeted treatment for autoimmune illnesses that selectively targets and neutralizes disease-causing substances or cells. These biologic medicines function by attaching to certain antigens, such as tumor necrosis factor (TNF), interleukins, or B-cells, which play an important role in the inflammatory process of autoimmune disorders [43]. By inhibiting these sites, mAbs can considerably lower inflammation and disease activity. Adalimumab and infliximab are two examples of rheumatoid arthritis treatments, whereas rituximab is used to treat multiple sclerosis and systemic lupus erythematosus [44]. These medicines provide more precise therapy choices with possibly fewer negative effects than standard immunosuppressive medications.

Small molecule Inhibitor: Small molecule inhibitors are a new type of targeted treatment for autoimmune illnesses that aims to disrupt intracellular signaling pathways that contribute to inflammation and immunological responses. These inhibitors specifically target kinases, transcription factors, and other molecules implicated in the pathophysiology of autoimmune diseases [45]. Janus kinase (JAK) inhibitors, such as tofacitinib and baricitinib, have been found to treat rheumatoid arthritis and other autoimmune illnesses by inhibiting the JAK-STAT pathway, which is required for cytokine signaling [46]. These medicines have advantages over biology, such as oral delivery and a larger range of action, which may lead to better patient adherence and results (see **Table 3**).

Table 3. Small molecule inhibitors for various autoimmune disease.

Small Molecule Inhibitor	Target Pathway	Diseases Treated	Ref.
Tofacitinib	JAK-STAT pathway	Rheumatoid Arthritis, Psoriasis, Ulcerative Colitis	[31]
Baricitinib	JAK-STAT pathway	Rheumatoid Arthritis, Atopic Dermatitis	[31]
Upadacitinib	JAK-STAT pathway	Rheumatoid Arthritis, Psoriatic Arthritis	[31]
Ruxolitinib	JAK-STAT pathway	Myelofibrosis, Polycythemia Vera, Vitiligo	[32]
Filgotinib	JAK-STAT pathway	Rheumatoid Arthritis, Crohn's Disease	[32]

3.2. Stem cell therapy

Mechanisms and Efficacy: Stem cell therapy is a novel and promising treatment for autoimmune illnesses, aimed at restoring immunological tolerance and repairing damaged tissues. The basic method is the utilization of hematopoietic stem cells (HSCs) or mesenchymal stem cells (MSCs) to regulate the immune system and promote tissue regeneration. HSC transplantation regenerates the immune system by removing autoreactive immune cells and promoting the growth of new, healthy immune cells [47]. MSCs, on the other hand, have immunomodulatory capabilities that can help decrease inflammation and promote tissue healing [48]. Efficacy studies have yielded encouraging results in a variety of autoimmune diseases. For example, autologous HSC transplantation has shown considerable advantages in multiple sclerosis, including improved neurological function and decreased disease activity [49,50].

Similarly, MSC therapy has shown promise in treating systemic lupus erythematosus by decreasing disease activity and increasing kidney function [51].

3.3. Gene therapy

CRISPR and Gene Editing Techniques: CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) and other gene editing techniques have transformed the field of gene therapy, providing accurate, fast, and diverse tools for repairing genetic abnormalities that cause autoimmune illnesses. The most extensively used technology, CRISPR-Cas9, enables particular DNA sequence alterations by targeting and cutting the DNA at exact sites, allowing faulty genes to be repaired or deleted [52]. This method has demonstrated potential in treating numerous autoimmune disorders by altering genes critical for immune control and inflammatory responses [53]. For example, research have looked into using CRISPR to change genes involved with disorders such as Type 1 Diabetes, where it might possibly address immune system defects that result in the killing of insulin-producing cells [54]. Another example is altering genes implicated in multiple sclerosis to keep immune cells from attacking the myelin sheath [55].

Future Prospects and Ethical Considerations: The future of gene therapy, particularly with CRISPR and other gene editing technologies, seems extremely promising for treating autoimmune illnesses. Advances in these approaches may lead to lasting treatments by addressing genetic abnormalities at the source. Personalized gene therapy based on individual genetic profiles is also a promising option, with the potential to improve therapeutic efficacy while lowering side effects [56]. However, the use of CRISPR and gene editing presents several ethical concerns. One key issue is the possibility of off-target effects, in which unexpected genetic alterations occur, leading to unanticipated outcomes [57].

There are also larger ethical concerns concerning germline editing, which may influence future generations and raise problems about permission and the moral implications of genetic modifications [58].

Additional ethical problems to solve include ensuring fair access to these sophisticated medicines and limiting abuse of genetic enhancement [59].

4. Challenges in treatment of autoimmune diseases

4.1. Drug resistance

Drug resistance is a significant difficulty in the treatment of autoimmune illnesses, as patients may become less receptive to therapeutic treatments over time. This can happen because of genetic changes, changed medication metabolism, or immune system adaptations that reduce the treatment’s effectiveness [60]. For example, individuals with rheumatoid arthritis frequently acquire resistance to methotrexate and biological medicines, such as TNF inhibitors, prompting the adoption of alternative therapy or combination treatments [61]. Overcoming medication resistance necessitates continual study to better understand the underlying processes and create new treatment approaches.

4.2. Side effects and adverse reactions

Many autoimmune disease medications have considerable side effects and unpleasant responses, which can restrict long-term usage and lower patients' quality of life. Corticosteroids, for example, are excellent in reducing inflammation but can result in weight gain, osteoporosis, hypertension, and an increased susceptibility to infections [62]. Similarly, immunosuppressive drugs and biologics can raise the risk of infection and cancer [63]. Managing these adverse effects requires careful monitoring, dosage modifications, and, in some cases, medication cessation, all of which might complicate illness treatment.

4.3. Patient compliance

Patient compliance is another significant difficulty in the treatment of autoimmune illnesses. Chronic diseases frequently need long-term therapy, and patients may struggle to adhere owing to the complexity of treatment regimens, side effects, or lack of quick benefit [64]. Noncompliance can result in illness flare-ups, progression, and diminished therapy effectiveness. Patient education, simpler treatment regimens, regular follow-up, and support systems to address psychological and logistical hurdles to adherence are all effective strategies for improving compliance [65].

5. Role of Artificial Intelligence in autoimmune disease treatment

Figure 1 illustrates the integration of AI across multiple stages of autoimmune disease management.

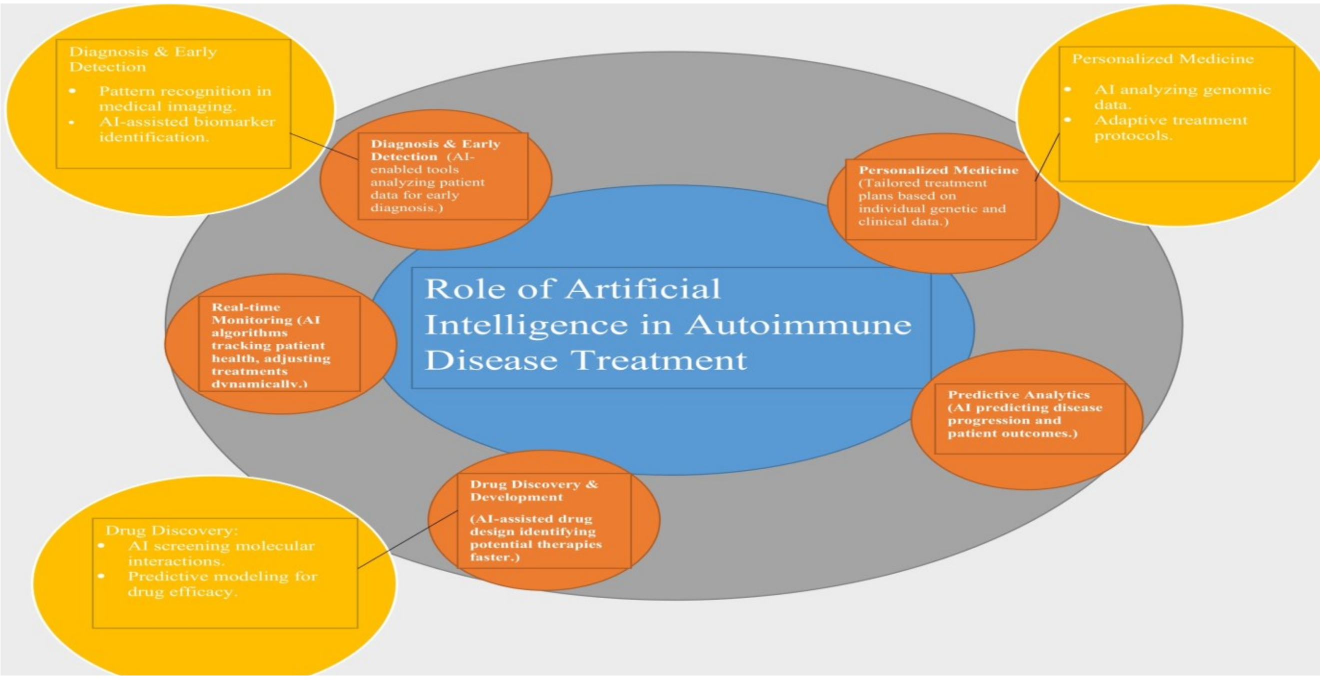

Figure 1. This figure visually explains how AI integrates into various stages of autoimmune.

Artificial intelligence (AI) and machine learning (ML) are rapidly being used to solve problems in autoimmune disease research and therapy. These technologies are being utilized to create prediction models for complicated autoimmune illnesses, stratify individuals, evaluate disease pathogenesis, and build personalized therapies [66]. AI has demonstrated potential in improving diagnosis, finding biomarkers, and creating novel treatments for autoimmune liver disorders [67].

5.1. AI in diagnostics

Early Detection through Machine Learning Algorithms: Artificial intelligence (AI), particularly machine learning (ML) algorithms, has greatly improved the early diagnosis of autoimmune disorders. Large datasets, such as clinical records, genetic information, and imaging data, may be analyzed using machine learning algorithms to uncover patterns and biomarkers related with autoimmune illnesses. This enables early detection and intervention, which is critical for treating illnesses such as rheumatoid arthritis, multiple sclerosis, and lupus. For example, AI systems have been trained to detect early indications of rheumatoid arthritis in imaging examinations with high accuracy, allowing for timely treatment commencement [68].

Predictive Analytics for Disease Progression: AI-powered predictive analytics helps patients with autoimmune illnesses predict disease development. Artificial intelligence models can anticipate flare-ups, disease activity, and future problems by analyzing longitudinal patient data such as clinical parameters, medication responses, and lifestyle variables. This enables doctors to create treatment strategies proactively and alter them in response to projected outcomes. Predictive models may accurately predict disease progression in multiple sclerosis and rheumatoid arthritis, enhancing patient care and prognosis [69].

5.2. AI in Personalized Medicine

AI-driven data analysis is critical in personalized medicine for autoimmune illnesses because it allows treatment strategies to be tailored to specific patients. Machine learning algorithms use massive volumes of data, including genetic, clinical, and lifestyle information, to detect trends and predict treatment outcomes. This personalized approach enables the selection of the most effective medicines for each patient, boosting results while minimizing side effects. For instance, AI algorithms may analyze genetic markers to identify which individuals are likely to react to various biologic medicines in rheumatoid arthritis, resulting in more accurate and successful treatment programs [70].

AI can also aid in optimizing medication doses and reducing adverse effects in the treatment of autoimmune illnesses. AI models can estimate the best medicine dose for each patient by combining patient-specific data like pharmacogenomics, metabolic rates, and treatment history. This method decreases the possibility of under- or overdose, which can result in treatment failure or serious adverse effects. AI-driven models have been found in studies to effectively anticipate optimal medication doses in illnesses such as systemic lupus erythematosus, enhancing therapeutic efficacy while minimizing side responses [71].

5.3. AI in drug discovery and development

Accelerating Research through AI-powered Simulations: Artificial intelligence

(AI) dramatically speeds up drug research and development procedures, notably through AI-powered simulations. These simulations employ machine learning techniques and computer models to anticipate how novel drug candidates will interact with biological systems, substantially decreasing the time and expense involved with conventional experimental procedures [72]. AI can simulate the interactions of hundreds of chemicals with target proteins, allowing researchers to select the most promising possibilities more effectively. This method is particularly useful for autoimmune illnesses, where understanding complicated immune responses is critical for creating successful therapeutics.

Identifying Novel Therapeutic Targets: AI also helps to uncover new treatment targets for autoimmune illnesses. By analyzing massive datasets from genomic research, proteomics, and patient records, AI algorithms can reveal previously unknown molecular pathways and targets implicated in disease etiology [73]. This may lead to the development of novel medications that regulate these targets, allowing for more effective therapies with fewer adverse effects. AI-driven research, for example, has revealed new targets for autoimmune disorders such as lupus and multiple sclerosis, opening the door to novel medicines [74].

5.4. AI in monitoring and management

Real-time Monitoring using AI-Enhanced Wearable Devices: AI-enhanced wearable devices enable real-time monitoring of patients with autoimmune illnesses, as well as continuous health data collecting and analysis. These gadgets, which are integrated with sensors and AI algorithms, can monitor a variety of physiological characteristics, including heart rate, temperature, physical activity, and specialized biomarkers [75]. This continuous monitoring enables early diagnosis of illness flares, evaluation of therapy efficacy, and prompt medical interventions. Wearables can monitor rheumatoid arthritis patients' joint mobility and inflammation levels, giving vital data to healthcare practitioners for altering treatment strategies [76].

AI in Patient Management and Telemedicine: AI contributes significantly to patient management and telemedicine by enhancing healthcare delivery and results. AI-powered systems analyze patient data from electronic health records, wearable devices, and other sources to give personalized treatment recommendations and care plans [71]. These technologies offer remote monitoring, decreasing the need for frequent hospital visits, which is especially advantageous for patients suffering from chronic autoimmune disorders. Furthermore, AI-powered telemedicine services can offer real-time consultations, diagnostics, and follow-ups, boosting access to healthcare and assuring ongoing patient care [77].

5.5. Incorporating explainable AI (XAI) in autoimmune disease treatment and personalized medicine

Explainable AI (XAI) is becoming increasingly important in healthcare, especially in difficult areas like autoimmune disease therapy and personalized medicine. XAI aims to make AI models more visible, interpretable, and intelligible, addressing one of the most common concerns about AI application in clinical settings: the "black-box" problem. Traditional AI algorithms sometimes create conclusions without providing explicit explanations of how certain outcomes are obtained. This lack of openness can undermine confidence and adoption, particularly in sensitive fields like healthcare, where understanding the reasoning behind therapeutic choices is critical [78].

In the context of autoimmune disorders, which entail complex immunological pathways and diverse patient reactions, XAI guarantees that healthcare practitioners can see and understand the decision-making process that underpins AI-generated forecasts and treatment recommendations. This not only increases trust in AI systems, but also enables doctors to check and cross-reference AI discoveries with their own knowledge. Furthermore, XAI improves the accountability of AI systems by allowing clinicians to deliver explicit explanations to patients, hence enhancing the overall patient experience and treatment adherence.

By using XAI, AI-driven models for personalized medicine can become more successful since they provide transparency in therapy selection based on unique patient profiles such as genetics, biomarkers, and illness history. Finally, XAI enhances decision-making and lowers possible biases, encouraging more equal healthcare delivery in autoimmune disease management and instilling greater trust in AI's ability to improve patient outcomes [79].

5.6. AI's impact on healthcare costs in autoimmune diseases

AI could drastically lower healthcare expenditures while increasing treatment efficiency for autoimmune disorders. AI can improve early diagnosis by utilizing predictive models, enabling prompt interventions and personalized therapies that save hospitalisations and long-term care costs. Automated methods for monitoring and managing patient data can improve administrative efficiency and resource allocation. Furthermore, AI-driven precision medicine reduces the need for trial-and-error in therapies, increasing patient outcomes and decreasing the total load on healthcare systems.

Figure 2 offers a concise comparison of the strengths and weaknesses of AI-driven and traditional treatment approaches in autoimmune disease management. It highlights AI's potential for personalized, data-driven care, improving treatment precision and outcomes. Meanwhile, traditional methods continue to provide time-tested efficacy but may lack the adaptability and predictive power of AI-based approaches.

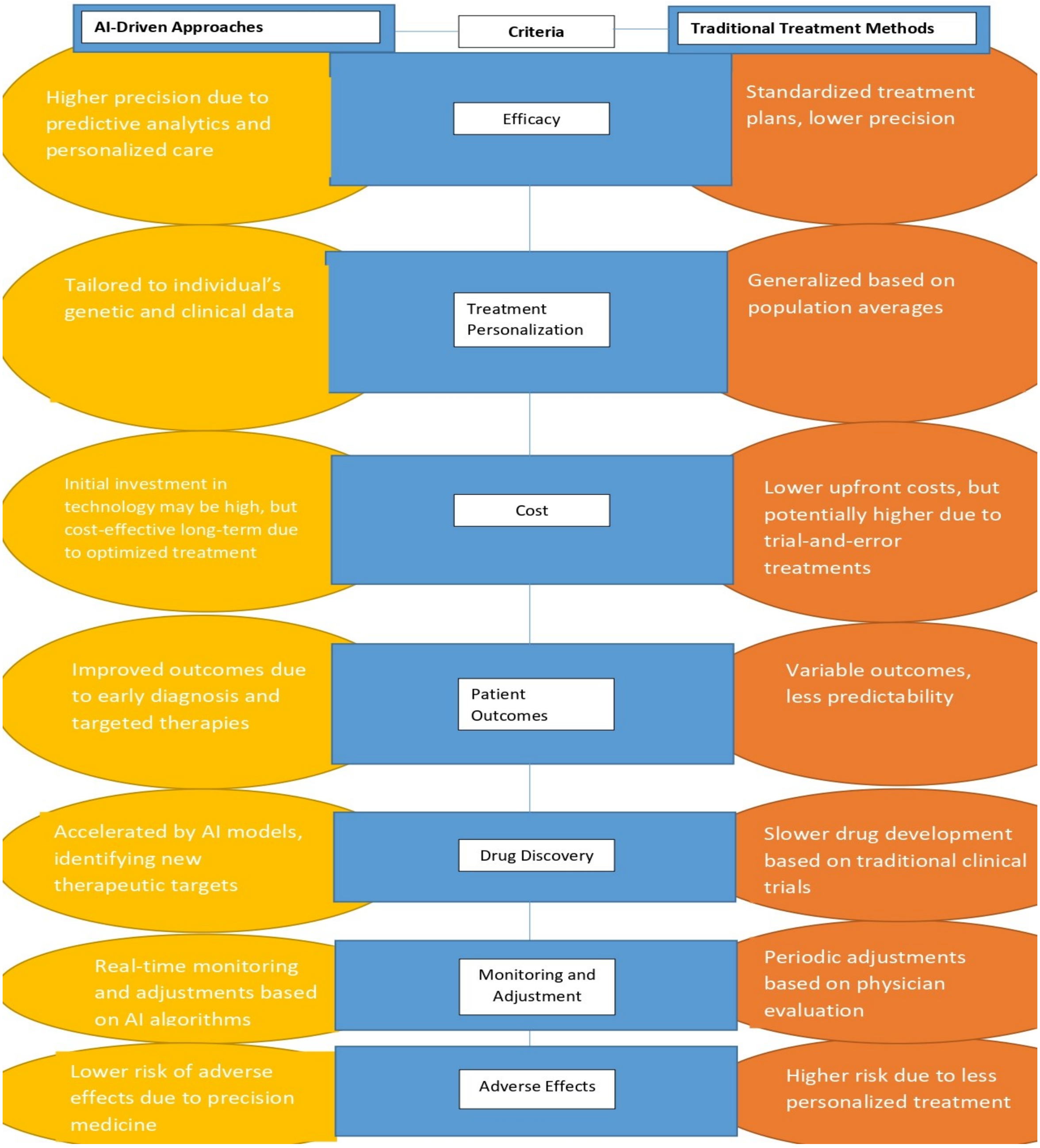

Figure 2. The figure provides a clear comparative view of the strengths and weaknesses of both AI-driven and traditional treatment approaches in autoimmune disease management.

6. Case studies and real-world applications

Table 4 outlines the applications of AI in managing autoimmune diseases, focusing on predictive diagnostics, personalized treatment, and disease monitoring.

AI deployment in the therapy of autoimmune illnesses has yielded encouraging outcomes in several case studies. One significant example is the employment of AI-powered prediction models to manage RA. Research done at Brigham and Women's Hospital employed machines learning algorithms to analyse electronic health information and accurately predict RA flare-ups. This enabled prompt therapy modifications, which reduced the intensity and frequency of flares [80]. Another example is the use of AI-enhanced imaging analysis in MS, where AI algorithms increased the accuracy of lesion identification in MRI images, allowing for earlier and more precise diagnosis [81]. The use of AI in the treatment of autoimmune illnesses has resulted in considerable improvements in patient outcomes and quality of life. AI-powered wearable devices, for example, continuously monitor patients' health data, allowing for early diagnosis of illness exacerbations and timely intervention. A study of lupus patients utilizing AI-enhanced wearables found improved illness management and fewer hospitalizations, resulting in better overall health outcomes [82]. Furthermore, AI-driven personalized medicine techniques have adjusted therapies to individual patients' requirements, optimizing therapeutic efficacy and minimizing unwanted effects, hence improving patients' quality of life [72].

Table 4. AI in autoimmune disease management.

Category	Description	References
Successful Implementation of AI in Autoimmune Disease Management	Predictive Models for RA Flares: Machine learning algorithms analyzed EHRs to predict rheumatoid arthritis flares at Brigham and Women's Hospital, enabling timely treatment adjustments.	[80]
	AI-Enhanced Imaging in MS: AI algorithms improved lesion detection in MRI scans for multiple sclerosis, facilitating earlier and more precise diagnosis.	[81]
Patient Outcomes and Quality of Life Improvements	AI-Powered Wearable Devices for Lupus: Continuous health monitoring via wearables led to improved disease management and reduced hospitalizations in lupus patients.	[83]
	Personalized Medicine in Autoimmune Diseases: AI-driven approaches tailored treatments to individual needs, optimizing efficacy and minimizing side effects.	[70]

The study emphasizes the limits of existing RA treatment techniques, despite advances in both Western and traditional medicine. AI technologies, particularly deep learning and cloud computing, provide potential for closing these gaps by improving drug development, understanding pharmacological processes, and optimizing diagnostic and therapy models. The future of RA therapy is expected to include AI integration, which will give more precise and personalized solutions, particularly for determining the mechanisms of ethnic medications such as Traditional Chinese and Tibetan medicine. This move will enhance both the diagnosis and management of RA worldwide [84].

Another work highlights the expanding application of AI-based prediction models to further precision medicine for autoimmune and autoinflammatory diseases (AIIDs). Recent advances in molecular profiling for disorders such as systemic lupus erythematosus (SLE), primary Sjögren syndrome (pSS), and rheumatoid arthritis (RA) have shown the complexities of these diseases, which include several proinflammatory pathways. Artificial intelligence models use omic data to stratify patients, discover causative pathways, and forecast treatment efficacy in virtual simulations. These developments enable personalized treatment methods by adapting medication options to patient characteristics, resulting in better AIID management [85].

The study found that machine learning models may accurately estimate flare probabilities in RA patients who are reducing biological disease-modifying antirheumatic medications (bDMARDs) during durable remission. Using clinical trial data, the researchers created a prediction model with an AUROC of 0.81, demonstrating its accuracy. Changes in bDMARD dosage, clinical disease activity, illness duration, and inflammatory markers all served as important predictors. The findings imply that machine learning is a viable and useful method for personalising RA therapy and controlling flare risk [80].

The case study showed that integrating ecological momentary assessment (EMA) data with machine learning algorithms can predict nonadherence to self-management behaviors, notably blood glucose monitoring (SMBG) and insulin delivery, in teenagers with type 1 diabetes (T1D). The machine learning models identified nonadherence events with good accuracy, although recall rates were lower. Important environmental and psychological elements, as well as time-related variables, were linked to self-management behavior. According to the study, this strategy might improve clinical decision-making, personalized patient care, and self-management by anticipating behavioral hazards. Future work should focus on increasing data collecting in order to develop and implement these prediction models [86].

The study identified an optimal decision rule that demonstrated continuous glucose monitoring (CGM) is more effective than blood glucose monitoring (BGM) in minimizing hypoglycemia in the majority of older adults with type 1 diabetes (T1D). Specifically, 81% of participants benefited from CGM, particularly those with more baseline hypoglycemia, undetectable C-peptide levels, greater glycemic variability, longer disease duration, and higher insulin pump usage. The study highlighted that CGM is a critical intervention for older adults at higher risk of hypoglycemia, and it emphasized the potential for using baseline characteristics, such as time-below-range and C-peptide levels, to inform personalized treatment decisions for better glucose management [87].

7. Shortcomings and benefits of Artificial Intelligence in autoimmune disease treatment

Artificial intelligence (AI) is quickly changing the landscape of autoimmune disease therapy by improving diagnostic accuracy, optimizing therapeutic options, and developing personalized medicine. However, like any emerging technology, it has both important benefits and limits that must be addressed to drive further development.

7.1. Benefits of AI in autoimmune disease treatment

Enhanced Diagnostic Accuracy: AI-based tools, particularly machine learning and deep learning algorithms, can process vast amounts of clinical, genomic, and proteomic data, allowing for earlier and more accurate diagnoses of autoimmune diseases such as rheumatoid arthritis and systemic lupus erythematosus. These models can detect patterns in patient data that conventional methods may miss, resulting in earlier intervention and better outcomes [88].

Personalized Medicine: AI can help with personalized treatment approaches by analyzing an individual’s genetic and molecular profile. By integrating omics data (genomics and proteomics), AI systems can find biomarkers linked with certain autoimmune illnesses, allowing for more accurate therapy. Personalized techniques eliminate the trial-and-error aspect of existing therapies, reducing adverse effects while increasing efficacy [89].

Drug Discovery and Repurposing: AI is revolutionizing drug research by predicting molecular interactions and discovering viable treatment candidates far more quickly than previous approaches. AI algorithms can also repurpose current medications by predicting their efficacy against autoimmune illnesses, drastically shortening development time [90].

Optimization of Treatment Protocols: AI can analyze patient reactions to various medications and optimise treatment procedures by predicting which treatments are most likely to be effective based on an individual's health data. This enables dynamic therapy adjustments, which improves results while lowering the likelihood of side effects [91].

7.2. Shortcomings of AI in autoimmune disease treatment

Data Privacy and Security: One of the most significant hurdles to using AI in healthcare is the possibility of data breaches. AI relies on massive datasets that contain sensitive personal health information, raising worries about data breaches, abuse, and compliance with health privacy rules such as HIPAA. It is vital to ensure that AI systems handle data safely while also respecting patient confidentiality.

Need for Large and High-Quality Datasets: AI systems require massive volumes of data to learn efficiently. Obtaining suitably big and representative datasets in the context of autoimmune illnesses can be difficult, particularly for uncommon autoimmune disorders. Furthermore, data quality issues (such as biases in data collecting or inconsistent medical records) might have a major influence on the accuracy of AI predictions.

Algorithmic Bias: AI systems are prone to biases, especially if the training data does not represent the overall population. For example, if an AI model is trained predominantly on data from a single demography (e.g., age group, gender, or ethnicity), it may underperform when applied to different populations. This bias might result in discrepancies in diagnosis and treatment, which is especially problematic with autoimmune illnesses that vary between populations.

Lack of Explainability: Many AI models, particularly deep learning algorithms, behave as "black boxes," which means therapists cannot simply analyze their decision-making processes. This lack of openness can be problematic in a medical context, because understanding the reasoning behind treatment recommendations is critical for both physicians and patients.

Regulatory and Ethical Challenges: The integration of AI in clinical practice raises ethical and regulatory challenges. AI systems must undergo rigorous testing and validation before they can be widely adopted in healthcare. Additionally, the use of AI in decision-making must balance clinical judgment and machine recommendations to ensure patient safety.

8. Limitations

Integrating AI in autoimmune disease treatment faces challenges including data privacy and security, data quality and availability issues, algorithm bias, lack of interpretability, difficulty in clinical integration, regulatory and ethical concerns, high implementation costs, and the need for extensive validation through clinical trials.

9. Future directions and research

9.1. Innovations on the horizon

Future advancements in AI for autoimmune disease treatment may include more sophisticated machine learning models that can predict disease flares with higher accuracy, development of AI-driven biomarkers for early diagnosis, and enhanced AI-powered personalized treatment plans. Additionally, the integration of AI with genomics and proteomics could lead to the discovery of novel therapeutic targets and tailored therapies.

9.2. Integrating AI with traditional treatment methods

The combination of AI with traditional treatment methods holds great potential for enhancing patient outcomes. AI can assist in optimizing drug dosages, predicting patient responses to treatments, and identifying the most effective treatment combinations. This integrated approach can provide more personalized and precise medical care, improving disease management and quality of life for patients.

9.3. Ethical and regulatory considerations

As AI continues to evolve in the medical field, addressing ethical and regulatory considerations will be crucial. Ensuring patient data privacy, avoiding algorithmic bias, and maintaining transparency in AI decision-making processes are essential. Developing comprehensive guidelines and regulations to oversee AI applications in healthcare will help in safeguarding patient welfare and foster trust in AI-driven medical solutions.

10. Conclusion

The integration of Artificial Intelligence into the treatment landscape of autoimmune diseases offers promising advancements towards more precise, efficient, and personalized healthcare. As AI continues to evolve, its potential to transform autoimmune disease management becomes increasingly evident, paving the way for improved patient outcomes and quality of life. This review aims to highlight the significance of these developments and encourage further research and collaboration in this dynamic field.

Acknowledgments: I would like to express my sincere gratitude to the members of the research team who contributed to the successful completion of this study. Their dedication, expertise, and commitment were instrumental in the realization of our research objectives. I am thankful to Prof. Said Al Ghenaimi, Dean of College of Applied and Health Sciences and Dr Nasiruddin Khan, HOD, Department of Medical Laboratory Sciences, A' Sharqiyah University for their guidance and support.

Conflict of interest: The authors declare no conflict of interest.

References

1. Mackay IR. Autoimmune Diseases. Encyclopedia of Immunology. Published online 1998: 287–292. doi:

10.1006/rwei.1999.0074
2. Rose NR, Bona C. Defining criteria for autoimmune diseases (Witebsky's postulates revisited). Immunology today. 1993; 14(9): 426–430.
3. Davidson A, Diamond B. Autoimmune Diseases. Mackay IR, Rosen FS, eds. New England Journal of Medicine. 2001; 345(5): 340–350. doi: 10.1056/nejm200108023450506
4. Ngo ST, Steyn FJ, McCombe PA. Gender differences in autoimmune disease. Frontiers in Neuroendocrinology. 2014; 35(3): 347–369. doi: 10.1016/j.yfrne.2014.04.004
5. Rosenblum MD, Remedios KA, Abbas AK. Mechanisms of human autoimmunity. Journal of Clinical Investigation. 2015; 125(6): 2228–2233. doi: 10.1172/jci78088
6. Ghobadinezhad F, Ebrahimi N, Mozaffari F, et al. The emerging role of regulatory cell-based therapy in autoimmune disease. Frontiers in Immunology. 2022; 13. doi: 10.3389/fimmu.2022.1075813
7. Pisetsky DS. Pathogenesis of autoimmune disease. Nature Reviews Nephrology. 2023; 19(8): 509–524. doi: 10.1038/s41581-023-00720-1
8. Vivas AJ, Boumediene S, Tobón GJ. Predicting autoimmune diseases: A comprehensive review of classic biomarkers and advances in artificial intelligence. Autoimmunity Reviews. 2024; 23(9): 103611. doi: 10.1016/j.autrev.2024.103611
9. Ahmed Z. Multi-omics strategies for personalized and predictive medicine: past, current, and future translational opportunities. Emerging Topics in Life Sciences. 2022; 6(2): 215–225. doi: 10.1042/etls20210244
10. Sahu A, Mishra J, Kushwaha N. Artificial Intelligence (AI) in Drugs and Pharmaceuticals. Combinatorial Chemistry & High Throughput Screening. 2022; 25(11): 1818–1837. doi:10.2174/1386207325666211207153943
11. Cortes A, Brown MA. Promise and pitfalls of the Immunochip. Arthritis Research & Therapy. 2010; 13(1): 101. doi: 10.1186/ar3204
12. Burmester GR, Pope JE. Novel treatment strategies in rheumatoid arthritis. The Lancet. 2017; 389(10086): 2338–48.
13. Dias SS, Isenberg DA. Advances in systemic lupus erythematosus. Medicine. 2014; 42(3): 126–133. doi: 10.1016/j.mpmed.2013.12.013
14. Jacobson DL, Gange SJ, Rose NR, et al. Epidemiology and Estimated Population Burden of Selected Autoimmune Diseases in the
15. Noseworthy JH, Lucchinetti C, Rodriguez M, et al. Multiple Sclerosis. New England Journal of Medicine. 2000; 343(13): 938–952. doi: 10.1056/nejm200009283431307
16. Cooper GS, Stroehla BC. The epidemiology of autoimmune diseases. Autoimmunity reviews. 2003;2(3): 119–125.
17. Petersen JS, Dyrberg T, Karlsen AE, Molvig J. Type 1 (insulin-dependent) diabetes mellitus: an overview of autoimmune disease and the role of interleukin-1. Diabetologia. 1997; 40(Suppl 2): S26–S34.
18. Lerner A, Jeremias P, Matthias T. The World Incidence and Prevalence of Autoimmune Diseases is Increasing. International Journal of Celiac Disease. 2015; 3(4): 151–155. doi: 10.12691/ijcd-3-4-8
19. Baldini E, Odorisio T, Tuccilli C, et al. Thyroid diseases and skin autoimmunity. Reviews in Endocrine and Metabolic Disorders. 2018; 19(4): 311–323. doi: 10.1007/s11154-018-9450-7
20. Singh M, Wambua S, Lee SI, et al. Autoimmune diseases and adverse pregnancy outcomes: an umbrella review. BMC Medicine. 2024; 22(1): 94. doi: 10.1186/s12916-024-03309-y
21. Kronzer VL, Kimbrough BA, Crowson CS, et al. Incidence, Prevalence, and Mortality of Dermatomyositis: A Population-Based Cohort Study. Arthritis Care & Research. 2022; 75(2): 348–355. doi: 10.1002/acr.24786
22. Chen J, Tian DC, Zhang C, et al. Incidence, mortality, and economic burden of myasthenia gravis in China: A nationwide population-based study. The Lancet Regional Health—Western Pacific. 2020; 5: 100063. doi: 10.1016/j.lanwpc.2020.100063
23. Caturegli P, De Remigis A, Rose NR. Hashimoto thyroiditis: Clinical and diagnostic criteria. Autoimmunity Reviews. 2014; 13(4–5): 391–397. doi: 10.1016/j.autrev.2014.01.007
24. Mahil SK, Wilson N, Dand N, et al. Psoriasis treat to target: defining outcomes in psoriasis using data from a real-world, population—based cohort study (the British Association of Dermatologists Biologics and Immunomodulators Register, BADBIR). British Journal of Dermatology. 2020; 182(5): 1158–1166. doi: 10.1111/bjd.18333
25. Bartalena L. Diagnosis and management of Graves disease: a global overview. Nature Reviews Endocrinology. 2013; 9(12): 724–734. doi: 10.1038/nrendo.2013.193
26. Bai JC, Ciacci C. World Gastroenterology Organisation Global Guidelines. Journal of Clinical Gastroenterology. 2017;

51(9): 755–768. doi: 10.1097/mcg.0000000000000919
27. Bugălă NM, Carsote M, Stoica LE, et al. New Approach to Addison Disease: Oral Manifestations Due to Endocrine Dysfunction and Comorbidity Burden. Diagnostics. 2022; 12(9): 2080. doi: 10.3390/diagnostics12092080
28. Voulgaris TA, Karamanolis GP. Esophageal manifestation in patients with scleroderma. World Journal of Clinical Cases. 2021; 9(20): 5408–5419. doi: 10.12998/wjcc.v9.i20.5408
29. Stavropoulos PG, Soura E, Kanelleas A, et al. Reactive Arthritis. Journal of the European Academy of Dermatology and Venereology. 2015; 29(3): 415–424. doi: 10.1111/jdv.12741
30. Benagiano M, Bianchi P, D'Elios MM, et al. Autoimmune diseases: Role of steroid hormones. Best Practice & Research Clinical Obstetrics & Gynaecology. 2019; 60: 24–34. doi: 10.1016/j.bpobgyn.2019.03.001
31. Williams DM. Clinical Pharmacology of Corticosteroids. Respiratory Care. 2018; 63(6): 655–670. doi: 10.4187/respcare.06314
32. Reichardt SD, Amouret A, Muzzi C, et al. The Role of Glucocorticoids in Inflammatory Diseases. Cells. 2021; 10(11): 2921. doi: 10.3390/cells10112921
33. Gisbert JP, Chaparro M. Systematic review with meta-analysis: inflammatory bowel disease in the elderly. Alimentary Pharmacology & Therapeutics. 2014; 39(5): 459–477. doi: 10.1111/apt.12616
34. Christofi T, Baritaki S, Falzone L, et al. Current Perspectives in Cancer Immunotherapy. Cancers. 2019; 11(10): 1472. doi: 10.3390/cancers11101472
35. Feldmann M, Maini RN. Anti-TNFα Therapy of Rheumatoid Arthritis: What Have We Learned? Annual Review of Immunology. 2001; 19(1): 163–196. doi: 10.1146/annurev.immunol.19.1.163
36. Li SJ, Perez-Chada LM, Merola JF. TNF Inhibitor-Induced Psoriasis: Proposed Algorithm for Treatment and Management. Journal of Psoriasis and Psoriatic Arthritis. 2018; 4(2): 70–80. doi: 10.1177/2475530318810851
37. Thoma LM, Li LC, White DK, et al. Physical Therapists Play a Key Role in the Comprehensive Management of Rheumatoid Arthritis. Arthritis Care & Research. 2023; 75(8): 1625–1628. doi: 10.1002/acr.25123
38. Göksel Karatepe A, Günaydin R, Türkmen G, et al. Effects of home-based exercise program on the functional status and the quality of life in patients with rheumatoid arthritis: 1-year follow-up study. Rheumatology International. 2009; 31(2): 171–176. doi: 10.1007/s00296-009-1242-7
39. Vojdani A, O'Bryan T, Green JA, et al. Immune Response to Dietary Proteins, Gliadin and Cerebellar Peptides in Children with Autism. Nutritional Neuroscience. 2004; 7(3): 151–161. doi: 10.1080/10284150400004155
40. Skoldstam L, Hagfors L, Johansson G.. An experimental study of a Mediterranean diet intervention for patients with rheumatoid arthritis. Annals of the Rheumatic Diseases. 2003; 62(3): 208–214. doi: 10.1136/ard.62.3.208
41. Sharif K, Watad A, Bragazzi NL, et al. Physical activity and autoimmune diseases: Get moving and manage the disease. Autoimmunity Reviews. 2018; 17(1): 53–72. doi: 10.1016/j.autrev.2017.11.010
42. Schäfer C, Keyßer G. Lifestyle Factors and Their Influence on Rheumatoid Arthritis: A Narrative Review. Journal of Clinical Medicine. 2022; 11(23): 7179. doi: 10.3390/jcm11237179
43. Dammes N, Peer D. Monoclonal antibody-based molecular imaging strategies and theranostic opportunities. Theranostics. 2020; 10(2): 938–955. doi: 10.7150/thno.37443
44. Keating GM. Panitumumab: a review of its use in metastatic colorectal cancer. Drugs. 2010; 70(8): 1059–1078. doi: 10.2165/11205090-000000000-00000
45. McElvaney OJ, Curley GF, Rose-John S, McElvaney NG. Interleukin-6: obstacles to targeting a complex cytokine in critical illness. Lancet Respir Med. 2021; 9(6): 643–654. doi: 10.1016/S2213-2600(21)00103-X
46. O'Shea JJ, Kontzias A, Yamaoka K, et al. Janus kinase inhibitors in autoimmune diseases. Annals of the Rheumatic Diseases. 2013; 72(suppl 2): ii111–ii115. doi: 10.1136/annrheumdis-2012-202576
47. Nash RA, Hutton GJ, Racke MK, et al. High-Dose Immunosuppressive Therapy and Autologous Hematopoietic Cell Transplantation for Relapsing-Remitting Multiple Sclerosis (HALT-MS). JAMA Neurology. 2015; 72(2): 159. doi: 10.1001/jamaneurol.2014.3780
48. Le Blanc K, Mougiakakos D. Multipotent mesenchymal stromal cells and the innate immune system. Nature Reviews Immunology. 2012; 12(5): 383–396. doi: 10.1038/nri3209
49. Burt RK, Shah SJ, Dill K, et al. Autologous non-myeloablative haemopoietic stem-cell transplantation compared with pulse cyclophosphamide once per month for systemic sclerosis (ASSIST): an open-label, randomised phase 2 trial. Lancet. 2011; 378(9790): 498–506. doi: 10.1016/S0140-6736(11)60982-3

50. Burt RK, Oliveira MC, Shah SJ, et al. Cardiac involvement and treatment-related mortality after non-myeloablative haemopoietic stem-cell transplantation with unselected autologous peripheral blood for patients with systemic sclerosis: a retrospective analysis. Lancet. 2013; 381(9872): 1116–1124. doi: 10.1016/S0140-6736(12)62114-X
51. Choi EW, Lee HW, Shin IS, et al. Comparative Efficacies of Long-Term Serial Transplantation of Syngeneic, Allogeneic, Xenogeneic, or CTLA4Ig-Overproducing Xenogeneic Adipose Tissue-Derived Mesenchymal Stem Cells on Murine Systemic Lupus Erythematosus. Cell Transplantation. 2016; 25(6): 1193–1206. doi: 10.3727/096368915x689442
52. Doudna JA, Charpentier E. The new frontier of genome engineering with CRISPR-Cas9. Science. 2014; 346(6213). doi: 10.1126/science.1258096
53. Sadelain M, Brentjens R, Rivière I. The promise and potential pitfalls of chimeric antigen receptors. Current Opinion in Immunology. 2009; 21(2): 215–223. doi: 10.1016/j.coi.2009.02.009
54. Singh DD, Hawkins RD, Lahesmaa R, et al. CRISPR/Cas9 guided genome and epigenome engineering and its therapeutic applications in immune mediated diseases. Seminars in Cell & Developmental Biology. 2019; 96: 32–43. doi: 10.1016/j.semcdb.2019.05.007
55. Van Zeebroeck L, Arroyo Hornero R, Côrte-Real BF, et al. Fast and Efficient Genome Editing of Human FOXP3+ Regulatory T Cells. Frontiers in Immunology. 2021; 12. doi: 10.3389/fimmu.2021.655122
56. Dai X, Blancafort P, Wang P, et al. Innovative Precision Gene-Editing Tools in Personalized Cancer Medicine. Advanced Science. 2020; 7(12). doi: 10.1002/advs.201902552
57. Bhattacharjee G, Gohil N, Khambhati K, et al. Current approaches in CRISPR-Cas9 mediated gene editing for biomedical and therapeutic applications. Journal of Controlled Release. 2022; 343: 703–723. doi: 10.1016/j.jconrel.2022.02.005
58. Guttinger S. Trust in Science: CRISPR–Cas9 and the Ban on Human Germline Editing. Science and Engineering Ethics. 2018; 24(4): 1077–1096. doi: 10.1007/s11948-017-9931-1
59. Gyngell C, Douglas T, Savulescu J. The Ethics of Germline Gene Editing. Journal of Applied Philosophy. 2017; 34(4): 498–513. doi: 10.1111/japp.12249
60. Firestein GS, McInnes IB. Immunopathogenesis of Rheumatoid Arthritis. Immunity. 2017; 46(2): 183–196. doi: 10.1016/j.immuni.2017.02.006
61. Smolen JS, Landewé RBM, Bijlsma JWJ, et al. EULAR recommendations for the management of rheumatoid arthritis with synthetic and biological disease-modifying antirheumatic drugs: 2019 update. Annals of the Rheumatic Diseases. 2020; 79(6): 685–699. doi: 10.1136/annrheumdis-2019-216655
62. Schäcke H, Döcke WD, Asadullah K. Mechanisms involved in the side effects of glucocorticoids. Pharmacol Ther. 2002; 96(1): 23–43. doi: 10.1016/s0163-7258(02)00297-8
63. Ramos-Casals M, Roberto-Perez-Alvarez, Diaz-Lagares C, et al. Autoimmune diseases induced by biological agents. Autoimmunity Reviews. 2010; 9(3): 188–193. doi: 10.1016/j.autrev.2009.10.003
64. Robin DiMatteo M, Giordani PJ, Lepper HS, et al. Patient Adherence and Medical Treatment Outcomes. Medical Care. 2002; 40(9): 794–811. doi: 10.1097/00005650-200209000-00009
65. Marengo MF, Suarez-Almazor ME. Improving treatment adherence in patients with rheumatoid arthritis: what are the options? International Journal of Clinical Rheumatology. 2015; 10(5): 345–356. doi: 10.2217/ijr.15.39
66. Moingeon P. Artificial intelligence-driven drug development against autoimmune diseases. Trends in Pharmacological Sciences. 2023; 44(7): 411–424. doi: 10.1016/j.tips.2023.04.005
67. Gerussi A, Scaravaglio M, Cristoferi L, et al. Artificial intelligence for precision medicine in autoimmune liver disease. Frontiers in Immunology. 2022; 13. doi: 10.3389/fimmu.2022.966329
68. Lundervold AS, Lundervold A. An overview of deep learning in medical imaging focusing on MRI. Zeitschrift für Medizinische Physik. 2019; 29(2): 102–127. doi: 10.1016/j.zemedi.2018.11.002
69. Miotto R, Wang F, Wang S, et al. Deep learning for healthcare: review, opportunities and challenges. Briefings in Bioinformatics. 2017; 19(6): 1236–1246. doi: 10.1093/bib/bbx044
70. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nature Medicine. 2019; 25(1): 44–56. doi: 10.1038/s41591-018-0300-7
71. MacEachern SJ, Forkert ND. Machine learning for precision medicine. Genome. 2021; 64(4): 416–425. doi: 10.1139/gen-2020-0131
72. Zhavoronkov A. Artificial Intelligence for Drug Discovery, Biomarker Development, and Generation of Novel Chemistry. Molecular Pharmaceutics. 2018; 15(10): 4311–4313. doi: 10.1021/acs.molpharmaceut.8b00930

73. Ekins S, Puhl AC, Zorn KM, et al. Exploiting machine learning for end-to-end drug discovery and development. Nature Materials. 2019; 18(5): 435–441. doi: 10.1038/s41563-019-0338-z
74. Mak KK, Pichika MR. Artificial intelligence in drug development: present status and future prospects. Drug Discovery Today. 2019; 24(3): 773–780. doi: 10.1016/j.drudis.2018.11.014
75. Davergne T, Rakotozafiarison A, Servy H, et al. Wearable Activity Trackers in the Management of Rheumatic Diseases: Where Are We in 2020? Sensors. 2020; 20(17): 4797. doi: 10.3390/s20174797
76. Kamei T, Kanamori T, Yamamoto Y, et al. The use of wearable devices in chronic disease management to enhance adherence and improve telehealth outcomes: A systematic review and meta-analysis. Journal of Telemedicine and Telecare. 2020; 28(5): 342–359. doi: 10.1177/1357633x20937573
77. Keesara S, Jonas A, Schulman K. Covid-19 and Health Care's Digital Revolution. New England Journal of Medicine. 2020; 382(23). doi: 10.1056/nejmp2005835
78. Alowais SA, Alghamdi SS, Alsuhebany N, et al. Revolutionizing healthcare: the role of artificial intelligence in clinical practice. BMC Medical Education. 2023; 23(1): 689. doi: 10.1186/s12909-023-04698-z
79. Yagin F, Alkhateeb A, Raza A, et al. An Explainable Artificial Intelligence Model Proposed for the Prediction of Myalgic Encephalomyelitis/Chronic Fatigue Syndrome and the Identification of Distinctive Metabolites. Diagnostics. 2023; 13(23): 3495. doi: 10.3390/diagnostics13233495
80. Vodencarevic A, Tascilar K, et al. Advanced machine learning for predicting individual risk of flares in rheumatoid arthritis patients tapering biologic drugs. Arthritis Research & Therapy. 2021; 23(1). doi: 10.1186/s13075-021-02439-5
81. Esteva A, Kuprel B, Novoa RA, et al. Dermatologist-level classification of skin cancer with deep neural networks. Nature. 2017; 542(7639): 115–118. doi: 10.1038/nature21056
82. Momtazmanesh S, Nowroozi A, Rezaei N. Artificial Intelligence in Rheumatoid Arthritis: Current Status and Future Perspectives: A State-of-the-Art Review. Rheumatology and Therapy. 2022; 9(5): 1249–1304. doi: 10.1007/s40744-022-00475-4
83. Mukherjee S, Suleman S, Pilloton R, et al. State of the Art in Smart Portable, Wearable, Ingestible and Implantable Devices for Health Status Monitoring and Disease Management. Sensors. 2022; 22(11): 4228. doi: 10.3390/s22114228
84. Wang S, Hou Y, Li X, et al. Practical Implementation of Artificial Intelligence-Based Deep Learning and Cloud Computing on the Application of Traditional Medicine and Western Medicine in the Diagnosis and Treatment of Rheumatoid Arthritis. Frontiers in Pharmacology. 2021; 12. doi: 10.3389/fphar.2021.765435
85. Danieli MG, Brunetto S, Gammeri L, Palmeri D, Claudi I, Shoenfeld Y, Gangemi S. Machine learning application in autoimmune diseases: State of art and future prospectives. Autoimmun Rev. 2024 Feb;23(2):103496. doi: 10.1016/j.autrev.2023.103496.
86. Zhang P, Fonnesbeck C, Schmidt DC, et al. Using Momentary Assessment and Machine Learning to Identify Barriers to Self-management in Type 1 Diabetes: Observational Study. JMIR mHealth and uHealth. 2022; 10(3): e21959. doi: 10.2196/21959
87. Kahkoska AR, Shah KS, Kosorok MR, et al. Estimation of a Machine Learning-Based Decision Rule to Reduce Hypoglycemia Among Older Adults With Type 1 Diabetes: A Post Hoc Analysis of Continuous Glucose Monitoring in the WISDM Study. Journal of Diabetes Science and Technology. 2024; 18(5): 1079–1086. doi: 10.1177/19322968221149040
88. Pillai AS. Utilizing Deep Learning in Medical Image Analysis for Enhanced Diagnostic Accuracy and Patient Care: Challenges, Opportunities, and Ethical Implications. Journal of Deep Learning in Genomic Data Analysis. 2021; 1(1): 1–7.
89. Johnson KB, Wei W, Weeraratne D, et al. Precision Medicine, AI, and the Future of Personalized Health Care. Clinical and Translational Science. 2021; 14(1): 86–93. doi: 10.1111/cts.12884
90. Yadav S, Singh A, Singhal R, et al. Revolutionizing drug discovery: The impact of artificial intelligence on advancements in pharmacology and the pharmaceutical industry. Intelligent Pharmacy. 2024; 2(3): 367–380. doi: 10.1016/j.ipha.2024.02.009
91. Alowais SA, Alghamdi SS, Alsuhebany N, et al. Revolutionizing healthcare: the role of artificial intelligence in clinical practice. BMC Medical Education. 2023; 23(1): 689. doi: 10.1186/s12909-023-04698-z