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Review Article

A Comprehensive Review of Adverse Drug Reactions: Classification, Mechanisms, and Prevention

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ABSTRACT

Adverse drug reactions pose a significant threat to therapeutic success and patient safety, despite considerable advances in drug development, regulatory oversight, and clinical monitoring systems. An adverse drug reaction is commonly defined as a harmful and unintended response to a medicinal product that occurs at doses normally used for prophylaxis, diagnosis, or treatment. These reactions contribute substantially to patient morbidity, hospital admissions, prolonged hospitalization, and increased healthcare costs, making them a major public health concern. This comprehensive review critically examines the broad spectrum of adverse drug reactions, with emphasis on their definitions, classification systems, and underlying molecular and clinical mechanisms. Contemporary classification approaches, including dose-related, nondose-related, time-related, and severity-based reactions, are discussed to facilitate better clinical understanding and recognition. The mechanistic basis of adverse drug reactions is explored in detail, encompassing pharmacodynamic and pharmacokinetic factors, immune-mediated hypersensitivity reactions, pharmacogenetic variability, and drug-drug and drug-food interaction-based mechanisms. In addition, the review analyses key patient-related and drug-related risk factors that influence individual susceptibility, such as age, genetic predisposition, comorbid conditions, polypharmacy, and organ dysfunction. Strategies for detection and assessment of adverse drug reactions, including clinical evaluation and standardized causality, severity, and preventability assessment tools, are also addressed. Preventive approaches form a central focus of this review and include rational prescribing, individualized therapy, therapeutic drug monitoring, patient education, and the expanding role of pharmacovigilance programs. By integrating mechanistic insights with clinical and preventive perspectives, this review aims to enhance awareness among healthcare professionals and researchers, ultimately supporting improved detection, management, and prevention of adverse drug reactions and promoting safer use of medicines.

Keywords: Adverse Drug Reaction, Adverse Drug Reactions (ADR) Prevention, Patient Safety.

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INTRODUCTION

Modern medicine is based on the careful balancing act between potential harm and therapeutic benefits. Despite the fact that pharmaceuticals have transformed healthcare and saved countless lives, they also come with risks that occasionally result in unforeseen outcomes. Millions of patients worldwide are impacted by adverse drug reactions, which put a great deal of strain on healthcare systems and constitute one of the biggest problems facing healthcare providers today (Lazarou *et al.*, 1998). These undesirable consequences can range from minor discomfort to potentially fatal conditions, and their effects go far beyond the suffering of a single patient to include more general-public health issues (Thacker, 2005).

Adverse drug reactions have a significant clinical and financial impact. Research has repeatedly demonstrated that Adverse Drug Reactions (ADRs) are among the most common reasons for hospital admissions in many nations, making up between 5 and 10 % of all hospitalizations. Adverse drug reactions frequently make a patient's course of treatment more difficult after they are admitted, necessitating longer hospital stays, more diagnostic tests, and interventions to control the reaction (Davies *et al.*, 2009). Healthcare costs are greatly increased by this series of events; estimates indicate that ADR-related costs total billions of dollars each year across healthcare systems. Adverse drug reactions contribute to patient morbidity beyond these quantifiable effects, impacting quality of life and occasionally resulting in death or permanent disability. The risk is increased for older patients and those with numerous comorbidities who frequently take multiple medications at once (Wooten, 2010).

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The field of pharmacovigilance, which protects drug safety throughout a medication's life cycle, emerged in response to these challenges. Pharmacovigilance is the science and practice of identifying, evaluating, comprehending, and preventing side effects or other drug-related issues. This field has grown more complex, incorporating active surveillance, signal detection algorithms, and risk management techniques in addition to passive reporting systems (Coleman and Pontefract, 2016). Early detection of adverse drug reactions is critical because it can help guide clinical decision-making and prevent major consequences. The development of predictive tools that can identify high-risk individuals before they suffer harm, as well as careful patient selection and dose adjustment, are examples of how prevention strategies have also changed over time. The field of pharmacogenomics and personalized medicine continues to grow (Kongkaew *et al*., 2008).

Definition of Adverse Drug Reaction

The first step in comprehending adverse drug reactions is to develop precise definitions that are applicable in a variety of healthcare environments and legal jurisdictions. The most popular definition of an adverse drug reaction is given by the World Health Organization, which defines it as "a reaction to a drug which is noxious and unintended, and which occurs at doses normally used in man for the prophylaxis, diagnosis, or therapy of disease, or for the modification of physiological function." (Pirmohamed *et al*., 2004). The detrimental character of the reaction, its unintentional occurrence, and its manifestation at therapeutic doses are all highlighted in this definition. Although these distinctions can occasionally become hazy in clinical practice, the inclusion of standard dosing in this definition is especially crucial because it separates actual adverse reactions from the effects of overdosing or medication errors (Pirmohamed *et al*., 2004).

This fundamental definition has been improved and modified by regulatory bodies worldwide to meet their unique reporting and monitoring requirements. Compared to the WHO definition, the US Food and Drug Administration define an adverse drug reaction as "any undesirable experience associated with the use of a medical product in a patient," which is a little more inclusive. Another viewpoint is provided by the International Council for Harmonization of Technical Requirements for Pharmaceuticals for Human Use, which defines ADRs in clinical research as "all noxious and unintended responses to a medicinal product related to any dose" (Shamim *et al*., 2016). These differing definitions represent various regulatory philosophies and pragmatic considerations, but they all have the same objective of identifying potentially dangerous drug effects to safeguard public health. The European Medicines Agency similarly emphasizes the relationship between the drug and the harmful effect, requiring that the reaction be at least possibly related to the medication (Edwards and Aronson, 2000).

An important distinction that often causes confusion is the difference between adverse drug reactions and adverse drug events. While the terms are sometimes used interchangeably in casual conversation, they represent fundamentally different concepts in the realm of drug safety. An adverse drug event is any untoward medical occurrence that happens while a patient is taking a medication, regardless of whether the medication caused the event. In contrast, an adverse drug reaction implies a causal relationship between the drug and the harmful outcome. This means that all adverse drug reactions are adverse drug events, but not all adverse drug events are adverse drug reactions. For example, if a patient taking an antibiotic breaks their arm in a fall, this would be an adverse drug event but not an adverse drug reaction, unless the antibiotic somehow contributed to the fall through dizziness or another mechanism (Rydberg *et al*., 2016).

Historical Background and Evolution of Adverse Drug Reactions Concept

Over the past century, the idea of adverse drug reactions and the methodical approach to drug safety have undergone significant change, largely due to tragic incidents that exposed the perilous effects of insufficient safety monitoring. There was little drug regulation in the early twentieth century, and little was known about the connection between drugs and their negative side effects. The idea of routinely checking for side effects did not exist, and drugs were frequently sold with scant scientific proof of their efficacy or safety. This was drastically altered in 1937 when the sulfanilamide tragedy in the United States claimed the lives of over 100 people, many of them children, due to the drug's formulation using the hazardous solvent diethylene glycol. The Federal Food, Drug, and Cosmetic Act of 1938, which mandated that manufacturers prove their products' safety before marketing them, was passed as a direct result of this tragedy (Naranjo *et al*., 1981).

However, the most pivotal moment in the history of drug safety came in the late 1950s and early 1960s with the thalidomide catastrophe, an event that fundamentally transformed how the world approached medication safety. Thalidomide was marketed in Europe, Canada, and other countries as a sedative and treatment for morning sickness in pregnant women, promoted as being remarkably safe. Yet this seemingly benign medication caused one of the most devastating drug disasters in history, resulting in thousands of children being born with severe limb malformations known as phocomelia, along with damage to internal organs (Naranjo *et al*., 1981). The tragedy was particularly heartbreaking because it was preventable with proper testing, and it exposed critical gaps in drug development and approval processes. The United States largely escaped the disaster thanks to Frances Oldham Kelsey at the FDA, who refused to approve thalidomide due to concerns about inadequate safety data, a decision that saved countless American families from tragedy (Hallas *et al*., 1990).

Global drug regulation underwent profound changes because of the tragedy of thalidomide. The United States passed the Kefauver-Harris Amendment in 1962, requiring pharmaceutical companies to demonstrate both safety and efficacy before putting their products on the market and requiring them to notify the FDA of any adverse effects. The pharmaceutical industry was drastically altered by this law, which also established new international guidelines for drug development. At about the same time, nations started setting up official pharmacovigilance programs to gather and examine adverse drug reaction reports in a methodical manner. In 1968, the World Health Organization established its Programme for International Drug Monitoring, which established a worldwide network for exchanging data regarding drug safety issues. This signalled the start of formal, global collaboration in recognizing and addressing drug hazards (Agbabiaka *et al*., 2008).

As new techniques and technologies improved our capacity to identify and comprehend adverse drug reactions, the evolution continued over the ensuing decades. Sophisticated databases and signal detection techniques were developed in the 1,980 and 1,990 s, enabling the identification of possible safety concerns from massive amounts of spontaneous reports. The field of pharmacogenomics emerged with the growth of molecular biology and genetics, providing an understanding of why some people have negative reactions while others do not. More recently, pharmacovigilance has expanded to include real-time monitoring and predictive modelling of drug safety issues thanks to the integration of big data analytics, artificial intelligence, and electronic health records. Every development has strengthened systems intended to shield patients from avoidable harm by building on the lessons learned from previous tragedies. Pharmacovigilance is a sophisticated, scientifically based field today (Budnitz *et al*., 2011).

Classification of Adverse Drug Reactions

ABCDEF Classification

Although additional classes have since been added, an ADR is commonly categorized as a "type A" or "type B" reaction (Figure 1).

Type A (Augmented)

These reactions are typically dose-dependent and result from the drug's normal pharmacological effects being exaggerated at a typical therapeutic dose. These effects are linked to low mortality rates, happen often, and are predictable.

Examples include drug-induced liver damage, a well-known type A reaction that can be brought on by an acetaminophen overdose; phototoxicity and tooth yellowing from tetracycline exposure; nephrotoxicity from aminoglycosides; and digestive side effects like erosive gastritis, peptic ulcer disease, and bleeding ulcers brought on by NSAID therapy (Woo *et al*., 2020).

Dry mouth, which is linked to tricyclic antidepressants, is one example of a type A reaction that is unrelated to the intended pharmacological action of the medication (Bardolia *et al*., 2020).

Type B (Bizarre) Reactions

The drug's direct pharmacological effects do not predict these novel reactions. These may be discovered for the first time after a medication has been used for its intended purpose because they are far less common and not uncommon.

Examples include hypersensitivity reactions like anaphylaxis to β-lactam antibiotics, such as penicillins and cephalosporins, idiosyncratic reactions like malignant hyperthermia with anaesthetics, intolerance reactions or low tolerance threshold to drugs (β-lactams, macrolide, tetracyclines, anti-HIV drugs, and anticancer antibiotics and tyrosine kinase inhibitors), idiosyncratic reactions, such as a drug-induced liver injury due to carbamazepine, felbamate, isoniazid, infliximab, immune-mediated (allergic) reactions due to penicillins, fluoroquinolones, vancomycin, curare mimetics, chloramphenicol-induced aplastic anaemia, and rifampicin- and isoniazid-induced hepatitis (Kongkaew *et al*., 2013).

Type C (Continuing) Reactions

Following their occurrence, these ADRs continue for a considerable amount of time.

Examples include the suppression of the hypothalamic-pituitary-adrenal axis by corticosteroids and the use of bisphosphonates that causes osteonecrosis of the jaw.

Type D (Delayed) Reactions

These ADRs noticeably take some time to manifest after drug use. Furthermore, those may be too difficult to identify due to their timing. Examples include teratogenesis from common antiepileptics (fetal hydantoin syndrome), tardive dyskinesia, a late form of extrapyramidal side effect of first-generation antipsychotic agents, leucopenia that may develop up to 6 weeks after a dose of lomustine, and carcinogenesis from immunosuppressants (Laatikainen *et al*., 2021).

Type E (End-of-Use) Reactions

These result from abruptly stopping a drug.

Examples include withdrawal syndrome from benzodiazepines, myocardial ischaemia after stopping β-blockers, and tension, insomnia, and perceptual abnormalities after stopping benzodiazepines. with opioids (Zaij *et al*., 2023).

Type F (Failure of Therapy) Reactions

These ADRs are caused by unanticipated therapy failure, in which a medication's effectiveness unintentionally rises or falls.

Examples include reduced drug clearance through dialysis and plasmapheresis, reduced drug efficacy due to drug interactions that change metabolism, the impact of critical illness on protein binding and elimination, and reduced antibiotic effect due to resistance (meropenem, linezolid, and colistin, penicillin, cephalosporins, fluoroquinolones, and macrolides) (Tanwar *et al*., 2023).

Classification Based on Severity (Mild, Moderate, Severe)

The degree to which an ADR causes harm is referred to as its severity. It indicates the severity of the reaction, which can range from minor discomfort to potentially fatal situations. Regardless of the result or length of the reaction, severity is rated according to increasing degrees of harm (Table 1).

The usual classifications for severity are mild, moderate, severe, or life-threatening. Seriousness does not always indicate a serious reaction. It directs clinical management decisions, like changing medications or adjusting dosages. Severity Grading: There are three primary categories into which severity is frequently divided (Patel and Patel, 2016).

Mild

Although noticeable, the symptoms are not bothersome. Usually, neither stopping the medication nor seeking medical attention is necessary due to the adverse drug reaction. As an illustration, consider mild drug-induced nausea or headaches (Aronson and Ferner, 2005).

Moderate

The symptoms are more severe and could cause problems with day-to-day activities. The medication may not need to be stopped, but the patient may require symptomatic treatment or dose modification. For instance, exhaustion or lightheadedness that causes daily activities to be interrupted (Aronson and Ferner, 2005).

Severe

The symptoms are incapacitating and restrict regular activities. Medical intervention is frequently necessary, and stopping the medication may be necessary. For instance, severe bleeding brought on by anticoagulants, severe allergic reactions, or severe hypertension (Moore *et al*., 1998).

Life-threatening

To avoid death or permanent disability, medical attention must be given right away. For instance, severe arrhythmias, anaphylactic shock, or severe respiratory depression (Micaglio *et al*., 2021).

Clinical example

Mild adverse drug reactions

Using an antihistamine causes a patient to have mild dry mouth, which has little effect on their overall health.

Moderate adverse drug reactions

An antihypertensive causes severe dizziness in a patient, necessitating a dose reduction.

Severe adverse drug reactions

When a statin causes serious liver damage, the patient must stop taking it right away and be admitted to the hospital (Pirmohamed and Park, 2001).

Mechanisms of Adverse Drug Reactions

Depending on the drug's nature, patient-related factors, and the biological pathways involved, adverse drug reactions can occur through a variety of mechanisms. In general, there are two types of adverse drug reaction mechanisms: pharmacological and nonpharmacological. It is easier to anticipate, avoid, and manage ADRs in clinical practice when these mechanisms are understood.

Pharmacological Mechanisms

The known pharmacodynamic or pharmacokinetic characteristics of a medication cause predictable, dose-dependent side effects known as pharmacological adverse drug reactions. These reactions are typically caused by effects on nontarget tissues or an exaggeration of the medication's therapeutic action (Wilke *et al*., 2007).

Exaggerated Pharmacological Effect

These reactions happen when a drug's intended pharmacological action gets out of control. They are frequently observed in cases of increased sensitivity, drug accumulation, or overdose. Hypoglycaemia brought on by excessive glucose-lowering effects of insulin or sulfonylureas is a clinical example. In a similar vein, warfarin therapy may result in excessive anticoagulation and bleeding.

Off-Target or Secondary Pharmacological Effects

Adverse effects can result from certain drugs interacting with tissues or receptors other than their intended target. For instance, because they block muscarinic receptors in nontarget organs, anticholinergic medications like atropine can result in dry mouth, blurred vision, constipation, and urine retention. Because they block beta-2 receptors in the lungs, nonselective β-blockers such as propranolol can cause bronchoconstriction in asthmatic patients (Salas *et al*., 2022).

Table 1: Common organ systems affected by Adverse Drug Reactions (ADRs).

Organ System	Common Types of ADRs	Frequently Implicated Drug Classes	Clinical Manifestations	Severity Range
Dermatologic (Skin)	Maculopapular Rash, Urticaria, Photosensitivity, Stevens-Johnson Syndrome, Toxic Epidermal Necrolysis, Fixed Drug Eruption, Exfoliative Dermatitis.	Antibiotics (Especially B-Lactams, Sulfonamides), Anticonvulsants, Allopurinol, NSAIDS, Antifungals.	Skin Redness, Itching, Hives, Blistering, Peeling, Discoloration, Increased Sensitivity to Sunlight, Widespread Skin Involvement with Mucosal Lesions in Severe Cases.	Mild To Severe (Life-Threatening in SJS/TEN).
Gastrointestinal	Nausea, Vomiting, Diarrhoea, Constipation, Peptic Ulceration, Gastrointestinal Bleeding, Hepatotoxicity, Pancreatitis, Pseudomembranous Colitis.	NSAIDs, Opioids, Antibiotics, Chemotherapy Agents, Corticosteroids, Antiretrovirals, Metformin, Certain Antihypertensives.	Abdominal Pain, Altered Bowel Habits, Loss of Appetite, Bleeding (Visible or Occult), Jaundice, Elevated Liver Enzymes, Severe Abdominal Pain Radiating to Back in Pancreatitis.	Mild to Severe (Potentially Life-Threatening with Liver Failure or Severe Bleeding).
Cardiovascular	Arrhythmias, Qt Prolongation, Hypotension, Hypertension, Heart Failure, Myocarditis, Cardiomyopathy, Thromboembolism.	Antiarrhythmics, Certain Antibiotics (Fluoroquinolones, Macrolides), Antipsychotics, Chemotherapy Agents (Anthracyclines), B-Blockers, Diuretics, Oral Contraceptives.	Palpitations, Chest Pain, Syncope, Shortness of Breath, Edema, Irregular Heartbeat, Sudden Cardiac Death in Severe Cases.	Moderate To Severe (Potentially Fatal).
Respiratory	Bronchospasm, Interstitial Pneumonitis, Pulmonary Fibrosis, Acute Respiratory Distress Syndrome, Pulmonary Edema, Cough.	ACE inhibitors, β-Blockers, Amiodarone, Methotrexate, Bleomycin, Nitrofurantoin, Aspirin and NSAIDS in Aspirin-Sensitive Asthmatics.	Persistent Dry Cough, Wheezing, Shortness of Breath, Rapid Breathing, Chest Tightness, Progressive Dyspnea, Reduced Exercise Tolerance.	Mild To Severe (Life-Threatening in ARDS).
Renal (Kidney)	Acute Kidney Injury, Chronic Kidney Disease, Interstitial Nephritis, Electrolyte Imbalances, Nephrotic Syndrome, Renal Tubular Damage.	NSAIDS, Aminoglycoside Antibiotics, Ace Inhibitors, Arbs, Diuretics, Lithium, Chemotherapy Agents, Contrast Media.	Decreased Urine Output, Edema, Elevated Serum Creatinine and Blood Urea Nitrogen, Electrolyte Abnormalities, Protein in Urine, Acute Renal Failure Requiring Dialysis.	Moderate To Severe (Potentially Irreversible).

Organ System	Common Types of ADRs	Frequently Implicated Drug Classes	Clinical Manifestations	Severity Range
Haematological (Blood)	Anaemia, Leucopenia, Neutropenia, Thrombocytopenia, Agranulocytosis, Aplastic Anaemia, Haemolytic Anaemia, Coagulopathy.	Chemotherapy Agents, Anticonvulsants, Antibiotics (Chloramphenicol, Sulfonamides), Antithyroid Drugs, Clozapine, NSAIDS, Anticoagulants, Antiplatelet Agents.	Fatigue, Weakness, Frequent Infections, Fever, Easy Bruising, Petechiae, Bleeding, Pallor, Life-Threatening Infections or Bleeding in Severe Cases.	Moderate To Severe (Potentially Fatal).
Hepatic (Liver)	Hepatocellular Injury, Cholestatic Injury, Mixed Hepatotoxicity, Drug-Induced Hepatitis, Cirrhosis, Acute Liver Failure.	Acetaminophen, Isoniazid, Statins, Certain Antibiotics, Antiretrovirals, Anabolic Steroids, Methotrexate, Herbal Supplements.	Jaundice, Dark Urine, Pale Stools, Right Upper Quadrant Pain, Elevated Transaminases and Bilirubin, Coagulopathy, Hepatic Encephalopathy in Severe Cases.	Mild to Severe (Potentially Fatal, May Require Transplantation).
Neurological	Seizures, Peripheral Neuropathy, Extrapyramidal Symptoms, Serotonin Syndrome, Neuroleptic Malignant Syndrome, Confusion, Headache, Dizziness.	Antipsychotics, Antidepressants, Certain Antibiotics (Fluoroquinolones), Chemotherapy Agents (Platinum Compounds, Vinca Alkaloids), Anticonvulsants, Opioids.	Tremors, Rigidity, Involuntary Movements, Altered Mental Status, Seizures, Numbness and Tingling in Extremities, Muscle Rigidity with Hyperthermia in Severe Syndromes.	Mild To Severe (Potentially Fatal in Severe Syndromes).
Endocrine/Metabolic	Hyperglycaemia, Hypoglycaemia, Thyroid Dysfunction, Adrenal Suppression, Osteoporosis, Weight Gain, Electrolyte Disturbances, Metabolic Syndrome.	Corticosteroids, Antidiabetic Agents, Antipsychotics, Thiazide Diuretics, Lithium, Amiodarone, Protease Inhibitors.	Abnormal Blood Glucose Levels, Changes in Weight, Fatigue, Heat or Cold Intolerance, Bone Fractures, Symptoms Related to Electrolyte Imbalances, Cushingoid Features.	Mild to severe (Potentially Life-Threatening with Severe Hypoglycaemia or Electrolyte Imbalances).
Immunologic/Allergic	Anaphylaxis, Serum Sickness, Drug-Induced Lupus, Hypersensitivity Syndrome (Dress), Vasculitis.	Antibiotics (Especially B-Lactams), Aspirin, Nsaids, Allopurinol, Anticonvulsants, Biologics, Procainamide, Hydralazine.	Rapid Onset of Hives, Angioedema, Bronchospasm, Hypotension, Shock in Anaphylaxis; Fever, Rash, Joint Pain, Lymphadenopathy in Serum Sickness and Dress; Systemic Lupus-Like Symptoms.	Moderate to Severe (Anaphylaxis Is Life-Threatening).

Organ System	Common Types of ADRs	Frequently Implicated Drug Classes	Clinical Manifestations	Severity Range
Musculoskeletal	Myopathy, Rhabdomyolysis, Tendinopathy, Tendon Rupture, Drug-Induced Lupus, Osteoporosis, Muscle Cramps.	Statins, Fibrates, Fluoroquinolone Antibiotics, Corticosteroids, Colchicine, Bisphosphonates.	Muscle Pain, Weakness, Elevated Creatine Kinase, Dark Urine from Myoglobinuria, Tendon Pain and Swelling, Reduced Bone Density, Pathological Fractures.	mild to severe (rhabdomyolysis can cause acute kidney injury).
Psychiatric/Behavioural	Depression, Anxiety, Psychosis, Suicidal Ideation, Mood Changes, Insomnia, Vivid Dreams, Cognitive Impairment.	Corticosteroids, Interferons, Certain Antihypertensives (B-Blockers), Antimalarials (Mefloquine), Isotretinoin, Varenicline, Some anticonvulsants.	Changes in Mood, Altered Sleep Patterns, Confusion, Hallucinations, Paranoia, Social Withdrawal, Expressed Thoughts of Self-Harm.	Mild to Severe (Potentially Fatal with Suicide).
Ophthalmologic (Eyes)	Blurred Vision, Dry Eyes, Cataracts, Glaucoma, Retinal Toxicity, Corneal Deposits, Optic Neuritis.	Corticosteroids, Antimalarials (Chloroquine, Hydroxychloroquine), Ethambutol, Tamoxifen, Anticholinergics, Amiodarone.	Vision changes, Eye Pain, Increased Intraocular Pressure, Difficulty with Colour Vision, Permanent Vision Loss in Severe Cases, Sensitivity to Light.	Mild to Severe (Potentially Irreversible Vision Loss).
OTIC (Ears)	Ototoxicity (Hearing loss and/or Vestibular damage), Tinnitus, Vertigo.	Aminoglycoside Antibiotics, Loop Diuretics, Platinum-Based Chemotherapy Agents, Aspirin (High Doses), Vancomycin.	Ringing in Ears, Hearing Loss, Dizziness, Balance Problems, Nausea from Vestibular Dysfunction.	Mild to Severe (may be Permanent and Disabling).

Abbreviations: ADRs: Adverse Drug Reactions.

Pharmacokinetic-Related Reactions

Toxicity may result from changes in drug distribution, metabolism, excretion, or absorption. Aminoglycoside antibiotics, for example, can build up in patients with renal impairment and cause ototoxicity and nephrotoxicity. Another illustration is the increased toxicity of phenytoin because of hepatic metabolism becoming saturated at higher dosages (Kulldorff *et al.*, 2013).

Drug-Drug Interactions

Adverse reactions can arise from pharmacological interactions that increase or decrease the effects of a drug. One well-known example is the higher risk of bleeding that occurs when warfarin and antibiotics that block its metabolism are taken together. When benzodiazepines and opioids are used together, respiratory depression and excessive sedation may result.

Non-pharmacological Mechanisms

In general, non-pharmacological adverse drug reactions are unpredictable, unclearly dose-dependent, and frequently unconnected to the known pharmacological action of the medication. Immune responses, genetic factors, or aberrant patient susceptibility all have an impact on these reactions.

Immunologically Mediated Reactions

These reactions fall under the category of hypersensitivity reactions and are caused by immune system activation. IgE-mediated type I reactions, such as those caused by penicillin allergies, can cause urticaria, angioedema, or anaphylaxis. Antibody-mediated cytotoxicity, like haemolytic anaemia brought on by methyldopa, is a feature of type II reactions. Immune complex deposition causes type III reactions, such as serum sickness with specific antibiotics. Type IV reactions, like contact dermatitis brought

on by topical medications, are cell-mediated, delayed reactions (Murphy *et al.*, 2023).

Idiosyncratic Reactions

Unusual patient susceptibility can result in idiosyncratic reactions, which are uncommon and unpredictable. These reactions have nothing to do with pharmacological action or dosage. Aplastic anaemia brought on by chloramphenicol is one clinical example. Isoniazid-induced liver damage in vulnerable people is another illustration.

Genetically Determined Reactions

Adverse reactions may result from genetic variations that affect drug metabolism and response. For instance, when exposed to medications like sulfonamides or primaquine, patients with glucose-6-phosphate dehydrogenase deficiency may experience haemolysis. Because of decreased drug clearance, slow acetylators may be more toxic when taking isoniazid (Malki and Pearson, 2020).

Intolerance and Pseudoallergic Reactions

Tinnitus brought on by low aspirin dosages is an example of intolerance, which is an exaggerated reaction to a medication at normal doses. Although they are similar to allergic reactions, pseudoallergic reactions do not involve immune mechanisms. Red man syndrome, a condition where vancomycin infusion causes flushing and hypotension, is one example.

Risk Factors for Adverse Drug Reactions

Patient characteristics (e.g., age, sex, ethnicity, coexisting disorders, genetic or geographic factors) and medication characteristics (e.g., type of medication, route of administration, dosage, bioavailability, treatment duration) affect the incidence and severity of ADRs. Older adults and those with polypharmacy are more at risk. It is unclear how much the incidence of ADRs is caused by prescriber errors and patient non-compliance with the recommended medication regimen (Rakshith, Nair, Ranganath, and Halagali, 2024).

Common risk factors or high-risk patient populations include:

- Older adults.
- Children.
- Renal or Hepatic Impairment.
- Genetic Variations (e.g., Genetic variants that cause Abacavir Hypersensitivity).

Although comorbidities rather than age may be the main cause, older adults have higher rates and more severe ADRs (see Drug-Related Problems in Older Adults). According to the World Health Organization's pharmacovigilance database, patients over 75 years of age are primarily affected by fatal adverse drug reactions. The most frequent ADR-related reason for emergency department visits among older adults was the therapeutic use of anticoagulants and diabetes medications, according to the United States National Electronic Injury Surveillance system. Drug-related harm was also caused by the nontherapeutic use of sedative and hypnotic drugs like benzodiazepines and analgesics (Osanlou *et al.*, 2022).

Predisposing Factors of Adverse Drug Reactions

Certain fastors increase the likelihood of developing an adverse reaction.

1. Patient-related factors

- **Age:** Children and the Elderly are Particularly Susceptible.
- **Genetics:** Genetic Polymorphisms or Enzyme Deficiencies.
- **Gender:** Women may be more likely to have ADRs.
- **Pregnancy:** Changes in Physiology Raise the Risk. Hepatic, Cardiac, and Renal Conditions are Examples of Concurrent Diseases.

2. Drug-related factors

- Medications with a Narrow Therapeutic Index or High Dosages.
- Polypharmacy Raises the Possibility of Drug Interactions.
- Absorption and Metabolism are Impacted by the Administration Route.

3. Social and environmental factors

- Alcohol Consumption.
- Smoking.
- Exposure to chemicals or pollutants.

Detection and Assessment of Adverse Drug Reactions

Patient safety, sensible pharmacotherapy, and efficient pharmacovigilance all depend on the identification and evaluation of adverse drug reactions. Healthcare practitioners can determine a link between drug exposure and unfavourable outcomes, evaluate the clinical impact, and put suitable preventive measures into place by using a methodical approach to identifying and assessing ADRs. For this purpose, several complementary techniques are employed (Waller and Evans, 2003).

Clinical Observation and Patient Reporting

The foundation for identifying ADRs in both inpatient and outpatient settings are clinical observation. After administering medication, medical professionals keep an eye out for any new or worsening symptoms, unexpected clinical signs, abnormal laboratory results, or changes in physiological parameters. Improvement following dose reduction or drug withdrawal is assessed, as is the temporal correlation between drug initiation and the onset of symptoms. Since patients are frequently the first to notice subjective or early symptoms like nausea, headache, dizziness, rashes, exhaustion, or mood swings, patient reporting is equally important. ADR detection can be improved through symptom diaries, medication history reviews, and structured patient interviews. To identify uncommon, delayed, or previously unreported ADRs, spontaneous reporting systems that gather ADR reports from medical professionals and patients make a substantial contribution to national and international pharmacovigilance databases (Khan *et al*., 2024).

Causality Assessment Scales

Determining the possibility that a particular medication caused the observed adverse reaction is the goal of causality assessment. Ten weighted questions make up the Naranjo causality assessment scale, a popular questionnaire-based tool that assesses things like temporal relationship, alternative causes, dose-response relationship, prior patient experience, and dechallenge and rechallenge outcomes. ADRs are categorized as definite, probable, possible, or doubtful based on their overall score. The causality assessment system of the World Health Organization-Uppsala Monitoring Center classifies reactions as certain, probable or likely, possible, unlikely, conditional or unclassified, and unassessable based on clinical judgment and available data. Large pharmacovigilance databases and standard clinical practice are two areas where this approach is especially helpful (Zhou *et al*., 2015).

Severity Assessment Scales

The degree of clinical harm brought on by an ADR and how it affects patient care are determined by severity assessment. Based on factors like the need for treatment modification, additional therapeutic intervention, hospitalization, extended hospital stays, permanent disability, or life-threatening outcomes, the Hartwig and Siegel severity assessment scale divides ADRs into mild, moderate, and severe categories. Clinical response, resource allocation, and risk communication are all prioritized with the aid of severity assessment (Figures 2-3) (Gerogianni *et al*., 2018).

Preventability Assessment Methods

Preventability assessment determines whether proper prescription, monitoring, or patient education could have prevented an adverse drug reaction. ADRs are categorized as definitely preventable, probably preventable, or not preventable using the widely used Schumock and Thornton preventability scale. It takes into account things like improper medication selection, improper dosage, neglecting to monitor treatment, known drug interactions, contraindications, and patient non-compliance. In clinical settings, preventable adverse drug reactions can be minimized, medication safety systems can be strengthened, and prescribing practices can be improved with the help of preventability analysis (Figure 4) (Patel and Patel, 2016).

Management of Adverse Drug Reactions

Reducing patient harm, easing symptoms, averting complications, and preventing the reaction from happening again are the main goals of managing adverse drug reactions. The severity of the reaction, the patient's clinical state, and the therapeutic significance of the suspected medication all influence how an ADR is managed. Ensuring patient safety and optimizing treatment outcomes require prompt recognition and appropriate intervention (Venu and Vijendra, 2019).

Withdrawal or dose adjustment of the suspected drug

Finding and treating the suspected causative medication is the first and most crucial step in managing an adverse drug reaction. Reducing the dosage or temporarily stopping the medication may be enough to alleviate symptoms in mild to moderate reactions, especially if the reaction is dose-dependent and predictable. The offending drug must be stopped immediately and permanently in cases of severe or potentially fatal reactions. To preserve therapeutic efficacy, alternative drugs with a safer profile should be taken into account. The risk-benefit ratio must be carefully considered, particularly if the medication is necessary for the patient's condition (Suke *et al*., 2015).

Symptomatic and supportive treatment

The goal of symptomatic and supportive management is to stabilize the patient and lessen the clinical signs of the adverse reaction. Antihistamines for allergic reactions, antiemetics for nausea and vomiting, antipyretics for fever, and analgesics for pain management are a few examples of this. In moderate to severe cases, supportive care may be necessary, including oxygen therapy, haemodynamic support, and fluid and electrolyte management. Vital signs and pertinent laboratory parameters must be continuously monitored to evaluate recovery and identify problems early (Jeetu and Anusha, 2010).

Use of antidotes when available

Antidotes are a vital tool for reversing or neutralizing the effects of some medications in certain situations. Examples include N-acetylcysteine for paracetamol toxicity, flumazenil for benzodiazepine overdose, vitamin K for bleeding caused by warfarin, and naloxone for opioid toxicity. Antidotes can dramatically lower morbidity and mortality when administered on

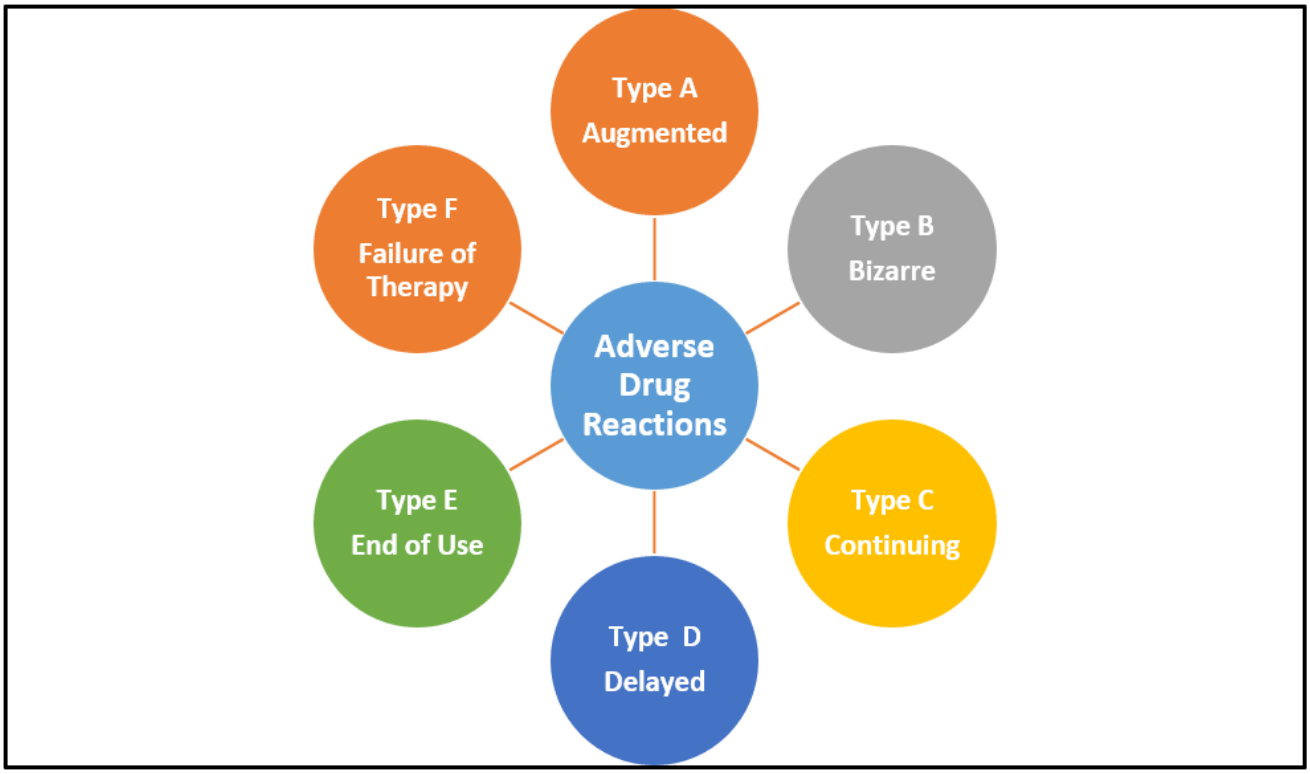

Figure 1: ABCDEF classification of adverse drug Reaction [17].

Causality term	Assessment criteria*
Certain	Event or laboratory test abnormality, with plausible time relationship to drug intake
	Cannot be explained by disease or other drugs
	Response to withdrawal plausible (pharmacologically, pathologically;
	Event definitive pharmacologically or phenomenologically (i.e. an objective and specific medical disorder or a recognized pharmacological phenomenon)
	Rechallenge satisfactory, if necessary
Probable / Likely	Event or laboratory test abnormality, with reasonable time relationship to drug intake
	Unlikely to be attributed to disease or other drugs
	Response to withdrawal clinically reasonable
	Rechallenge not required
Possible	Event or laboratory test abnormality, with reasonable time relationship to drug intake
	Could also be explained by disease or other drugs
	Information on drug withdrawal may be lacking or unclear
Unlikely	Event or laboratory test abnormality, with a time to drug intake that makes a relationship improbable (but not impossible)
	Disease or other drugs provide plausible explanations
Conditional / Unclassified	Event or laboratory test abnormality
	More data for proper assessment needed, or
	Additional data under examination
Unassessable / Unclassifiable	Report suggesting an adverse reaction
	Cannot be judged because information is insufficient or contradictory
	Data cannot be supplemented or verified

* All points should be reasonable complied with

Figure 2: Naranjo causality assessment scale (Zhou *et al*., 2015).

Hartwig's Severity Assessment Scale

Level 1	An ADR occurred but required no change in treatment with the suspected drug.
Level 2	The ADR required that treatment with the suspected drug be held, discontinued, or otherwise changed. No antidote or other treatment requirement was required. No increase in length of stay (LOS)
Level 3	The ADR required that treatment with the suspected drug be held, discontinued, or otherwise changed. AND/OR An Antidote or other treatment was required. No increase in LOS
Level 4	Any Level 3 ADR which increases length of stay by at least 10day. OR The ADR was the reason for the admission
Level 5	Any Level 4 ADR which requires intensive medical care
Level 6	The adverse reaction caused permanent harm to the patient
Level 7	The adverse reaction either directly or indirectly led to the death of the patient

Levels 1 and 2 – **Mild**; Levels 3 and 4- **Moderate**; Levels 5, 6 and 7-**Severe**

Figure 3: Hartwig and Siegel severity assessment scale (Gerogianni, Tsezou, and Dimas, 2018).

	Questions for assessment of preventability
Definitely preventable	
1.	Was there a history of allergy or previous reactions to the drug?
2.	Was the drug involved inappropriate for the patient's clinical condition?
3.	Was the dose, route or frequency of administration inappropriate for the patient's age, weight or disease state?
4.	Was a toxic serum drug concentration (or laboratory monitoring test) documented?
5.	Was there a known treatment for the Adverse Drug Reaction?
Probably preventable	
6.	Was required Therapeutic drug monitoring or other necessary laboratory tests not performed?
7.	Was a drug interaction involved in the ADR?
8.	Was poor compliance involved in the ADR?
9.	Were preventative measures not prescribed or administered to the patient?
Not preventable	
	If all above criteria not fulfilled

Figure 4: Schumock and Thornton preventability scale (Patel and Patel, 2016).

time. To use them safely, one must be aware of the proper timing, dosage, and contraindications (World Health Organization, 1972).

Rechallenge and desensitization

To verify causality, the suspected medication is reintroduced after the adverse reaction has subsided. When alternative therapies are scarce, this approach may be cautiously considered in mild, nonimmunological reactions, but it is typically avoided in severe or life-threatening reactions. Desensitization is a specialized process that is mainly used for immune-mediated reactions. Under strict medical supervision, the medication is given in progressively higher doses. This approach should only be used when the medication is absolutely necessary and there are no viable substitutes.

To guarantee patient safety and the best possible therapeutic results, effective management of adverse drug reactions

necessitates individualized clinical judgment, close observation, and a multidisciplinary approach (Shah *et al*., 2021).

Prevention of Adverse Drug Reactions

Adverse drug reaction prevention is essential to patient safety and high-quality medical care. Implementing preventive strategies is crucial because a significant percentage of ADRs are predictable and preventable, particularly those associated with medication errors, inappropriate prescribing, and insufficient monitoring. The frequency and severity of adverse drug reactions can be considerably decreased, and treatment outcomes can be enhanced, with a proactive, patient-centred approach.

Rational prescribing and dose individualization

The process of rational prescribing entails choosing the best drug based on a precise diagnosis, evidence-based recommendations, and a personal evaluation of patient characteristics. These variables include comorbid conditions, age, body weight, gender, genetic variability, and a history of adverse drug reactions. For medications with limited therapeutic ranges and in specific populations like children, the elderly, pregnant women, and critically ill patients, dosage customization is especially crucial. Pharmacokinetic parameters, disease severity, and renal and hepatic function-based modifications help reduce dose-related toxicity while preserving therapeutic efficacy. The risk of adverse drug reactions is further decreased by avoiding needless high dosages, extended therapy, and improper drug combinations (Nankervis *et al*., 2016).

Therapeutic drug monitoring

By ensuring that drug concentrations stay within the therapeutic window, therapeutic drug monitoring is essential for preventing adverse drug reactions. For drugs with limited therapeutic indexes, substantial interindividual variability, or known toxicity risks, this approach is particularly helpful. Early detection of supratherapeutic drug levels through routine monitoring enables prompt dose modification or drug discontinuation. In circumstances involving drug-drug interactions, altered metabolism, organ dysfunction, or long-term therapy, therapeutic drug monitoring is also helpful in lowering the risk of cumulative toxicity.

Avoidance of unnecessary polypharmacy

Adverse drug reactions are largely caused by polypharmacy, especially in older patients and those with numerous chronic illnesses. Medication nonadherence, additive adverse effects, and drug-drug interactions are all made more likely when multiple medications are used concurrently. Regular medication reviews, deprescribing unnecessary medications, and giving priority to treatments with the greatest clinical benefit are examples of preventive measures. Medication regimen simplification increases adherence while lowering the possibility of mistakes and unfavourable consequences (Shah *et al*., 2021).

Patient education and counselling

Since informed patients are more likely to use medications safely and effectively, patient education is a key component of ADR prevention. Clear instructions on dosage, timing, therapy duration, and potential side effects should be part of counselling. Patients should be urged to report any unusual symptoms as soon as possible and to refrain from abruptly stopping prescribed therapy, sharing drugs, or self-medicating. Additionally, education increases adherence and gives patients the confidence to take an active role in their care.

Role of clinical pharmacists and multidisciplinary teamsThrough medication reconciliation, potential interaction detection, dose optimization, and patient counselling, clinical pharmacists play a critical role in preventing adverse drug reactions. Medication safety is improved by their participation in therapeutic decision-making and clinical rounds. Coordinated care, efficient communication, and thorough monitoring are all encouraged by a multidisciplinary team approach that includes doctors, pharmacists, nurses, and other medical specialists. This cooperative approach enhances pharmacovigilance initiatives and promotes the early detection and avoidance of adverse drug reactions (Nankervis *et al*., 2016).

Role of pharmacovigilance in ADR prevention

By guaranteeing the ongoing monitoring, detection, assessment, and prevention of drug-related issues throughout a medication's life cycle, pharmacovigilance plays a critical role in the prevention of adverse drug reactions. By spotting safety issues that might not be apparent during preclinical research or clinical trials, it acts as a vital link between clinical practice, regulatory bodies, and public health.

National and international pharmacovigilance programs

National pharmacovigilance programs are designed to gather and examine reports of suspected adverse drug reactions as well as to keep an eye on the safety of medications within a nation. Hospitals, community pharmacies, and regulatory organizations work together in coordinated networks to carry out these programs. Global organizations that facilitate data sharing and signal detection between nations support pharmacovigilance efforts internationally. Rare, severe, or delayed adverse reactions that might only show up when a medication is used in large and diverse populations can be identified thanks to collaborative international systems. Such international collaboration strengthens drug safety surveillance and improves early warning capabilities (Purssell, 2019).

Spontaneous Reporting Systems

Pharmacovigilance relies heavily on spontaneous reporting systems. These systems depend on medical professionals and, occasionally, patients reporting suspected adverse drug reactions voluntarily. For the purpose of signal detection and analysis, reports are gathered in national databases and sent to international monitoring centres. Spontaneous reporting systems are very useful for detecting new safety signals, unexpected reactions, and changes in the benefit-risk profile of medications during postmarketing use, even though underreporting is still a problem.

Role of Healthcare Professionals In ADR Reporting

By spotting and reporting suspected adverse drug reactions, medical professionals-including doctors, pharmacists, nurses, and dentists-play a crucial part in pharmacovigilance. To identify possible drug-related harm, determine causality, and produce thorough and accurate reports, their clinical expertise is crucial. Patient safety outcomes are improved and pharmacovigilance data quality is strengthened when healthcare professionals actively participate (Kumar *et al*., 2022).

Contribution to regulatory decisions and safer drug use

By supporting actions like label updates, safety warnings, use restrictions, or the removal of medications from the market, pharmacovigilance data have a direct impact on regulatory decision-making. By reducing the possibility of avoidable adverse drug reactions, these strategies promote safer drug use, rational prescription, and public health protection.

FUTURE PERSPECTIVES AND CHALLENGES

With advancements in science, technology, and healthcare delivery, the field of adverse drug reaction prevention and drug safety is constantly changing. The prediction, detection, and prevention of adverse drug reactions can be enhanced by emerging approaches; however, a number of obstacles must be overcome to guarantee their successful application in clinical practice (Singh *et al*., 2020).

Understanding individual differences in drug response and vulnerability to adverse drug reactions has advanced significantly thanks to pharmacogenomics. Drug efficacy and toxicity can be greatly impacted by genetic differences in transporters, drug targets, and drug-metabolizing enzymes. By incorporating pharmacogenomic testing into standard clinical practice, the risk of ADRs can be decreased through individualized drug selection and dose optimization. Despite its potential, widespread adoption is hampered by issues like limited access to genetic testing, high costs, a lack of standardized guidelines, and low clinician awareness.

By examining vast and intricate datasets, artificial intelligence and machine-learning methods are being used more and more to forecast negative drug reactions. From pharmacovigilance databases, clinical records, and biomedical literature, these technologies can find hidden patterns, identify high-risk patients, and identify early safety signals. AI-based models can help with clinical decision-making and improve signal detection. Nonetheless, there are still a lot of difficulties with data quality, algorithm transparency, interpretability, and ethical issues (Ahmed Bakri and Jaly, 2023).

The widespread use of electronic health records has opened up new possibilities for tracking adverse drug reactions in real time. By integrating clinical decision support systems into EHRs, medical practitioners can be made aware of patient-specific risk factors, improper dosage, and possible drug interactions. Medication safety is enhanced by EHR-based systems; however, interoperability, data standardization, alert fatigue, and inadequate documentation are obstacles.

Clinical trial data is supplemented by real-world evidence from observational studies, registries, and postmarketing surveillance, which reflects actual drug use in a variety of populations. Real-world evidence improves our understanding of long-term safety, but to maximize its impact on drug safety and ADR prevention, issues like data heterogeneity, confounding factors, and regulatory acceptance must be carefully addressed (Shariff *et al*., 2018).

CONCLUSION

In clinical practice and public health, adverse drug reactions continue to be a serious problem that greatly increases patient morbidity, mortality, and healthcare expenses. Promoting the safe and efficient use of medications requires a thorough grasp of adverse drug reactions, including their classification, underlying mechanisms, risk factors, detection, assessment, and management. Early detection of ADRs through clinical observation, patient reporting, and structured assessment tools allows for prompt intervention and lowers the risk of severe consequences. Preventive measures that reduce the likelihood of predictable and avoidable adverse reactions include rational prescribing, dose individualization, therapeutic drug monitoring, and avoiding needless polypharmacy.

By enabling the ongoing monitoring of medications throughout their life cycle, pharmacovigilance plays a crucial part in enhancing drug safety. Early safety signal detection and well-informed regulatory decision-making are facilitated by the active involvement of healthcare professionals in ADR reporting, which is backed by national and international pharmacovigilance programs. New opportunities to improve ADR prediction and prevention are presented by developments in pharmacogenomics, artificial intelligence, electronic health records, and real-world evidence. To reach their full potential, however, issues with

data quality, standardization, accessibility, and integration into standard clinical practice must be resolved.

In conclusion, enhancing medication safety necessitates a proactive, multidisciplinary strategy that incorporates clinical knowledge, patient participation, strong pharmacovigilance systems, and cutting-edge technologies. Reducing the burden of adverse drug reactions requires strengthening education and awareness among healthcare professionals, encouraging sensible medication use, and fostering cooperation between regulatory bodies, physicians, and researchers. In the end, these coordinated initiatives will result in safer pharmacotherapy, better patient outcomes, and increased public trust in the use of medications.

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ABBREVIATIONS

CKD: Chronic Kidney Disease; **ESRD:** End-Stage Renal Disease; **GFR:** Glomerular Filtration Rate; **eGFR:** Estimated Glomerular Filtration Rate; **CKD-MBD:** Chronic Kidney Disease–Mineral and Bone Disorder; **PTH:** Parathyroid Hormone; **Ca:** Calcium; **PO4:** Phosphate; **Hb:** Hemoglobin; **BP:** Blood Pressure; **DM:** Diabetes Mellitus; **HTN:** Hypertension.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS CONTRIBUTION

Concept: Mohammed Ali, Design: Maher Unissa, Data acquisition: Maher Unissa, Manuscript preparation: Maher Unissa, Manuscript editing: Mohammed Ali, Manuscript review: Maher Unissa.

REFERENCES

Agbabiaka, T. B., Savović, J., & Ernst, E. (2008). Methods for causality assessment of adverse drug reactions: A systematic review. *Drug Safety*, *31*(1), 21-37. doi: 10.2165/00002018-200831010-00003, PubMed: 18095744

Ahmed Bakri, H., & Jaly, A. A. (2023). Antibiotics-related adverse drug reaction in a tertiary hospital in Saudi Arabia: A cohort, retrospective study. *Cureus*, *15*(5), e38431. doi: 10.7759/cureus.38431, PubMed: 37273353

Aronson, J. K., & Ferner, R. E. (2005). Clarification of terminology in drug safety. *Drug Safety*, *28*(10), 851-870. doi: 10.2165/00002018-200528100-00003, PubMed: 16180936

Bardolia, C., Matos, A., Michaud, V., Turgeon, J., Bain, K. T., & Amin, N. S. (2020). Utilizing pharmacogenomics to reduce adverse drug events. *American Journal of Biomedical Science & Research*, *11*(3). Retrieved from AJBSR.MS.ID, 258-261. doi: 10.34297/AJBSR.2020.11.001638. PubMed: 37649018

Budnitz, D. S., Lovegrove, M. C., Shehab, N., & Richards, C. L. (2011). Emergency hospitalizations for adverse drug events in older Americans. *New England Journal of Medicine*, *365*(21), 2002-2012. doi: 10.1056/NEJMsa1103053, PubMed: 22111719

Coleman, J. J., & Pontefract, S. K. (2016). Adverse drug reactions. *Clinical Medicine*, *16*(5), 481-485. doi: 10.7861/clinmedicine.16-5-481, PubMed: 27697815

Davies, E. C., Green, C. F., Taylor, S., Williamson, P. R., Mottram, D. R., & Pirmohamed, M. (2009). Adverse drug reactions in hospital in-patients: A prospective analysis of 3695 patient-episodes. *PLOS One*, *4*(2), e4439. doi: 10.1371/journal.pone.0004439, PubMed: 19209224

Edwards, I. R., & Aronson, J. K. (2000). Adverse drug reactions: Definitions, diagnosis, and management. *Lancet*, *356*(9237), 1255-1259. doi: 10.1016/S0140-6736(00)02799-9, PubMed: 11072960

FDA. "Adverse Event Reporting System (FAERS). Gerogianni, K., Tsezou, A., & Dimas, K. (2018 June). Drug-induced skin adverse reactions: The role of pharmacogenomics in their prevention. *Molecular Diagnosis and Therapy*, *22*(3), 297-314. doi: 10.1007/s40291-018-0330-3, PubMed: 29564734

Hallas, J., Harvald, B., Gram, L. F., Grodum, E., Brøsen, K., Haghfelt, T., & Damsbo, N. (1990 August). Drug related hospital admissions: The role of definitions and intensity of data collection, and the possibility of prevention. *Journal of Internal Medicine*, *228*(2), 83-90. doi: 10.1111/j.1365-2796.1990.tb00199.x, PubMed: 2394974

Jeetu, G., & Anusha, G. (2010). Pharmacovigilance: A worldwide master key for drug safety monitoring. *Journal of Young Pharmacists*, *2*(3), 315-320. doi: 10.4103/0975-1483.66802, PubMed: 21042493

Khan, M. A. A., Sara, T., & Babar, Z. U. D. (2024). Pharmacovigilance: The evolution of drug safety monitoring. *Journal of Pharmaceutical Policy and Practice*, *17*(1), 2417399. doi: 10.1080/20523211.2024.2417399, PubMed: 39450127

Kongkaew, C., Hann, M., Mandal, J., Williams, S. D., Metcalfe, D., Noyce, P. R., & Ashcroft, D. M. (2013 August). Risk factors for hospital admissions associated with adverse drug events. *Pharmacotherapy*, *33*(8), 827-837. doi: 10.1002/phar.1287, PubMed: 23686895

Kongkaew, C., Noyce, P. R., & Ashcroft, D. M. (2008). Hospital admissions associated with adverse drug reactions: A systematic review of prospective observational studies. *Annals of Pharmacotherapy*, *42*(7), 1017-1025. doi: 10.1345/aph.1L037, PubMed: 18594048

Kulldorff, M., Dashevsky, I., Avery, T. R., Chan, A. K., Davis, R. L., Graham, D., . (2013 May). Drug safety data mining with a tree-based scan statistic. *Pharmacoepidemiology and Drug Safety*, *22*(5), 517-523. doi: 10.1002/pds.3423, PubMed: 23512870

Kumar, S., Singh, R. K., Seth, R. N., & Sinha, R. I. (2022). A study of reporting pattern of adverse drug reactions in a tertiary care teaching hospital. *International Journal of Basic and Clinical Pharmacology*, *12*(1), 58-63. doi: 10.18203/2319-2003.ijbcp20223355

Laatikainen, O., Sneck, S., & Turpeinen, M. (2021). Medication-related adverse events in healthcare. *European Journal of Clinical Pharmacology*, *77*, 897-909. doi: 10.1007/s00228-021-03213-x

Lazarou, J., Pomeranz, B. H., & Corey, P. N. (1998). Incidence of adverse drug reactions in hospitalized patients: A meta-analysis of prospective studies. *JAMA*, *279*(15), 1200-1205. doi: 10.1001/jama.279.15.1200, PubMed: 9555760

Malki, M. A., & Pearson, E. R. (2020 June). Drug-drug-gene interactions and adverse drug reactions. *Pharmacogenomics Journal*, *20*(3), 355-366. doi: 10.1038/s41397-019-0122-0, PubMed: 31792369

Micaglio, E., Locati, E. T., Monasky, M. M., Romani, F., Heilbron, F., & Pappone, C. (2021 April 30). Role of pharmacogenetics in adverse drug reactions: An update towards personalized medicine. *Frontiers in Pharmacology*, *12*, 651720. doi: 10.3389/fphar.2021.651720, PubMed: 33995067

Moore, N., Lecointre, D., Noblet, C., & Mabille, M. (1998). Frequency and cost of serious adverse drug reactions in a department of general medicine. *British Journal of Clinical Pharmacology*, *45*(3), 301-308. doi: 10.1046/j.1365-2125.1998.00667.x, PubMed: 9517375

Murphy, R. M., Klopotowska, J. E., de Keizer, N. F., Jager, K. J., Leopold, J. H., Dongelmans, D. A., Schut, M. C. (2023). Adverse drug event detection using natural language processing: A scoping review of supervised learning methods. *PLOS One*, *18*(1), e0279842. doi: 10.1371/journal.pone.0279842, PubMed: 36595517

Nankervis, H., Thomas, K. S., Delamere, F. M. *et al.* (2016). *Scoping systematic review of treatments for eczema*. Southampton, UK: National Institute on Handicapped Research Journals Library.

Naranjo, C. A., Busto, U., Sellers, E. M., Sandor, P., Ruiz, I., Roberts, E. A., Greenblatt, D. J. (1981 August). A method for estimating the probability of adverse drug reactions. *Clinical Pharmacology and Therapeutics*, *30*(2), 239-245. doi: 10.1038/clpt.1981.154, PubMed: 7249508

Osanlou, R., Walker, L., Hughes, D. A., Burnside, G., & Pirmohamed, M. (2022 July 4). Adverse drug reactions, multimorbidity and polypharmacy: A prospective analysis of 1 month of medical admissions. *BMJ Open*, *12*(7), e055551. doi: 10.1136/bmjopen-2021-055551, PubMed: 35788071

Patel, T. K., & Patel, P. B. (2016). Incidence of adverse drug reactions in Indian hospitals: A systematic review of prospective studies. *Current Drug Safety*, *11*(2), 128-136. doi: 10.2174/1574886311066150921104523, PubMed: 26391424

Pirmohamed, M., & Park, B. K. (2001 June). Genetic susceptibility to adverse drug reactions. *Trends in Pharmacological Sciences*, *22*(6), 298-305. doi: 10.1016/s0165-6147(00)01717-x, PubMed: 11395158

Pirmohamed, M., James, S., Meakin, S., Green, C., Scott, A. K., Walley, T. J., Breckenridge, A. M. (2004). Adverse drug reactions as cause of admission to hospital: Prospective analysis of 18 820 patients. *BMJ*, *329*(7456), 15-19. doi: 10.1136/bmj.329.7456.15, PubMed: 15231615

Purssell, E. (2019). Antimicrobials. In *Understanding pharmacology in nursing practice* (pp. 147-165). Cham, Germany: Springer. doi: 10.1007/978-3-030-32004-1_6

Rakshith, U. R., Nair, S. P., Ranganath, A. H., & Halagali, P. (2024). Drug interactions: Mechanisms, assessment and management strategies. *Journal of Young Pharmacists*, *16*(3), 447-455. doi: 10.5530/jyp.2024.16.58

Retrieved from https://www.fda.gov/drugs/questions-and-answers-fdas-adverse-event-reporting-system-faers.

Rydberg, D. M., Holm, L., Engqvist, I., Fryckstedt, J., Lindh, J. D., Stiller, C. O., & Asker-Hagelberg, C. (2016). Adverse drug reactions in a tertiary care emergency

ward: A prospective study of reported adverse drug reactions. *PLOS One*, *11*(9), e0162948. doi: 10.1371/journal.pone.0162948, PubMed: 27622270

Salas, M., Petracek, J., Yalamanchili, P., Aimer, O., Kasthuril, D., Dhingra, S., Bostic, T. (2022 October). The use of artificial intelligence in pharmacovigilance: A systematic review of the literature. *Pharmaceutical Medicine*, *36*(5), 295-306. doi: 10.1007/s40290-022-00441-z, PubMed: 35904529

Shah, R., Parajuli, S. B., & Pokharel, S. (2021). Knowledge of adverse drug reactions reporting among doctors and nurses in a tertiary care hospital: A descriptive cross-sectional study. *JNMA; Journal of the Nepal Medical Association*, *59*(233), 22-25. doi: 10.31729/jnma.5386, PubMed: 34508460

Shamim, S., Sharib, S. M., Malhi, S. M., Muntaha, S. U., Raza, H., Ata, S., Hussain, M. (2016). Adverse drug reactions (ADRS) reporting: Awareness and reasons of under-reporting among health care professionals, a challenge for pharmacists. *SpringerPlus*, *5*(1), 1778. doi: 10.1186/s40064-016-3337-4, PubMed: 27795920

Shariff, U., Aboumarzouk, O. M., & Nelson, R. L. (2018). Antibiotics for the management of constipation predominant irritable bowel syndrome and chronic constipation. *Cochrane Database of Systematic Reviews*, *2018*(10), CD007518. doi: 10.1002/14651858.CD007518.pub2

Singh, A., Jain, A., Soni, M., Shukla, P., Lahon, J., & Verma, A. K. (2020). Pattern of adverse drug reactions reported at a tertiary care teaching hospital in northern India. *International Journal of Basic and Clinical Pharmacology*, *9*(4), 625-629. doi: 10.18203/2319-2003.ijbcp20201189

Suke, S. G., Kosta, P., & Negi, H. (2015). Role of pharmacovigilance in India: An overview. *Online Journal of Public Health Informatics*, *7*(2), e223. doi: 10.5210/ojphi.v7i2.5595, PubMed: 26392851

Tanwar, D., Yadav, R. P., Saroha, A., & Sharma, P. (2023). Adverse drug reactions: Mechanisms, detection and prevention strategies. *International Journal for Research Publication and Seminar*, *14*(1), 425-431. doi: 10.36676/jrps.v14.i1.1613

Thacker, P. D. (2005). New technologies detect adverse drug reactions earlier. *JAMA*, *294*(23), 2983-2985. doi: 10.1001/jama.294.23.2983

Venu, D., & Vijendra, R. (2019). Furosemide induced bullous pemphigoid: A case report. *International Journal of Basic and Clinical Pharmacology*, *8*(6), 1444, doi: 10.18203/2319-2003.ijbcp20192218

Waller, P. C., & Evans, S. J. W. (2003). A model for the future conduct of pharmacovigilance. *Pharmacoepidemiology and Drug Safety*, *12*(1), 17-29. doi: 10.1002/pds.773, PubMed: 12616844

Wilke, R. A., Lin, D. W., Roden, D. M., Watkins, P. B., Flockhart, D., Zineh, I., Krauss, R. M. (2007 November). Identifying genetic risk factors for serious adverse drug reactions: Current progress and challenges. *Nature Reviews. Drug Discovery*, *6*(11), 904-916. doi: 10.1038/nrd2423, PubMed: 17971785

Woo, S. D., Yoon, J., Doo, G. E., Park, Y., Lee, Y., Lee, S. H., Ye, Y. M. (2020). Common causes and characteristics of adverse drug reactions in older adults: A retrospective study. *BMC Pharmacology and Toxicology*, *21*(1), 87. doi: 10.1186/s40360-020-00464-9, PubMed: 33303036

Wooten, J. M. (2010). Pharmacist involvement in the prevention and management of adverse drug reactions. *American Journal of Health-System Pharmacy*, *67*(10), 805-812. doi: 10.2146/ajhp090394

World Health Organization (1972). International drug monitoring: The role of national centres. *World Health Organization Technical Report Series*. Geneva: World Health Organization, (498).

Zaij, S., Pereira Maia, K., Leguelinel-Blache, G., Roux-Marson, C., Kinowski, J. M., & Richard, H. (2023). Intervention of pharmacist included in multidisciplinary team to reduce adverse drug event: A qualitative systematic review. *BMC Health Services Research*, *23*(1), 927. doi: 10.1186/s12913-023-09512-6

Zhou, Z. W., Chen, X. W., Sneed, K. B., Yang, Y. X., Zhang, X., He, Z. X., Zhou, S. F. (2015 April). Clinical association between pharmacogenomics and adverse drug reactions. *Drugs*, 75(6), 589-631. doi: 10.1007/s40265-015-0375-0, PubMed: 25895462

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