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Review of medicines approved by the Food and Drug Administration from 2012 to 2024

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The aim. To describe the key characteristics of medical products approved by the Food and Drug Administration (FDA) and released by pharmaceutical companies from 2012 to 2024.

Materials and methods. The analysis is based on data from FDA publications related to the approval of medical products from 2012 to 2024. The products were systematized by year, pathway and reason for approval, nature of the active substance (synthetic, semi-synthetic, natural or biological) and target disease (indication for use) in accordance with the codes of the Anatomical Therapeutic Chemical (ATC) classification.

Results. During the analyzed period, the FDA approved a significant number of medicines, while maintaining a stable proportion of small molecules with a significant upward trend in the number of approved biologicals (monoclonal antibodies, CAR-T, siRNA, gene therapy, etc.). The largest proportion was accounted for by antitumor drugs and immunomodulators (group L according to ATC), demonstrating steady growth with projected growth in the future. Interest in drugs for the treatment of metabolic disorders and diseases of the nervous system remained steadily high, with the emergence of innovative therapeutic approaches. A gradual increase in the number of repositionings and extensions of indications was noted. The COVID-19 pandemic did not have a significant impact on the overall structure of approvals, and only two specific medicines for the treatment of COVID-19 were approved. There has been an increase in approvals for orphan diseases and the emergence of innovative therapeutic approaches: gene therapy, RNA interference, cell technologies, and bispecific antibodies.

Conclusion. In the period from 2012 to 2024, the pharmaceutical industry has seen a fundamental shift towards biotechnological development methods, personalized medicine, and targeted therapy. During the period under review, the

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proportion of small molecule approvals remained fairly stable, but a steady (compared to previous periods) increase in the number of biotechnology product approvals (monoclonal antibodies, gene and RNA therapy) can be noted. The largest increase was noted in class L (antitumor drugs and immunomodulators), which reflects the focus of global pharmaceutical companies on the fundamental study and discovery of pharmacotherapy opportunities in the oncology and immunity. It is necessary to note the trend towards the development of drugs for the treatment of rare (orphan) diseases. In the field of therapy for metabolic disorders, during the specified period, drugs were approved that revolutionized understanding of an entire cluster of diseases and approaches to therapy, and a new standard of therapy was formed due to SGLT2 inhibitors and agonists of the incretin system receptors, including molecules with a multi-targeted effect. The COVID-19 pandemic led to a limited number of drug approvals for the treatment of this infection but thanks to it, the "door" to the development of new generation vaccines has been opened, which are largely fundamentally different from those currently existing. The discovery of new means to combat infectious agents of various nature (bacteria, protozoa, viruses, fungi, and parasites) is also one of the priority goals of pharmaceutical companies, as evidenced by a significant proportion of approvals of drugs with a similar effect. In terms of "reasons for registration," the main share fell on original drugs; the contribution of new combinations and dosage forms was at its peak in the middle of the period and then decreased. Due to the expiration of patent protection for many drugs and the accumulation of data on their effects in the post-marketing period, a gradual increase in the number of repositionings and extensions of indications can be logically noted.

Keywords: FDA; ATC; targeted therapy; trends in drug design; approved medicines; new medicines

Abbreviations: HSC — hematopoietic stem cells; GIT — gastrointestinal tract; iDPP4 — dipeptidyl peptidase 4 inhibitor; iSGLT2 — sodium-glucose cotransporter 2 inhibitor; LH — luteinizing hormone; mRNA — messenger ribonucleic acid; NSCLC — non-small cell lung cancer; DM — diabetes mellitus; DM1 — type 1 diabetes mellitus; DM2 — type 2 diabetes mellitus; SMA — spinal muscular atrophy; FSH — follicle-stimulating hormone; COPD — chronic obstructive pulmonary disease; CMV — cytomegalovirus; CNS — central nervous system; CD — cluster of differentiation; CGRP — calcitonin gene-related peptide; FDA — Food and Drug Administration; IFN — interferon; IL — Interleukin; mAb — monoclonal antibody; siRNA — small interfering ribonucleic acid; VEGF — vascular endothelial growth factor.

Обзор лекарственных средств, одобренных FDA в период с 2012 по 2024 годы

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Цель. Описать ключевые характеристики лекарственных препаратов, одобренных Управлением по санитарному надзору за качеством пищевых продуктов и медикаментов (Food and Drug Administration, FDA), выпущенных фармацевтическими компаниями за период 2012–2024 гг.

Материалы и методы. Анализ произведен по данным из публикаций FDA, относящихся к одобрению лекарственных препаратов за период с 2012 по 2024 год. Препараты систематизировали по году, пути и поводу одобрения, характеру действующего вещества (синтетический, полусинтетический, природный или биологический) и целевому заболеванию (показание к применению) в соответствии с кодами анатомо-терапевтическо-химической классификации (АТХ).

Результаты. За анализируемый период FDA одобрило значительное количество лекарственных препаратов, при этом сохранялась стабильная доля малых молекул при значимом тренде роста числа одобренных биологических препаратов (моноклональные антитела, CAR-T, siRNA, генная терапия и др.). Наибольшую долю составили противоопухолевые препараты и иммуномодуляторы (группа L по АТХ), демонстрирующие устойчивый рост с прогнозируемым ростом в будущем. Стабильно высоким остался интерес к препаратам для лечения метаболических нарушений и заболеваний нервной системы с появлением инновационных терапевтических подходов. Отмечен постепенный рост числа репозиционирований и расширений показаний. Пандемия COVID-19 не оказала существенного влияния на общую структуру одобрений и было одобрено лишь два специфических препарата для лечения COVID-19. Отмечен рост одобрений для орфанных заболеваний и появление инновационных терапевтических подходов: генной терапии, РНК-интерференции, клеточных технологий и биспецифических антител.

Заключение. В период с 2012 по 2024 год в фармацевтической индустрии отмечается фундаментальный сдвиг в сторону биотехнологических методов разработки, персонализированной медицины и таргетной терапии. В течение рассматриваемого периода доля одобрения малых молекул оставалась достаточно стабильной, но можно отметить устойчивый (по сравнению с предыдущими периодами) рост числа одобрений биотехнологических продуктов (моноклональные антитела, генная и РНК-терапия). Наибольший прирост отмечен в классе L (противоопухолевые препараты и иммуномодуляторы), что отражает фокус внимания глобальных фармацевтических компаний к фундаментальному изучению и открытию возможностей фармакотерапии в области онкологии и иммунитета. Необходимо отметить тренд на разработку лекарственных средств для лечения редких (орфанных) заболеваний. В области терапии метаболический расстройств, за указанный период, одобрены препараты, которые перевернули понимание целого кластера болезней и подходов к терапии, сформировался новый стандарт терапии за счёт ингибиторов SGLT2 и агонистов рецепторов инкретиновой системы, включая молекулы оказывающее мультитаргетное влияние. Пандемия COVID-19 привела к ограниченному числу одобрений лекарственных препаратов для лечения инфекции, благодаря ей приоткрыта «дверца» к разработке вакцин нового поколения, во многом принципиально отличающихся от существующих в настоящее время. Открытие новых средств для борьбы с инфекционными агентами различной природы (бактерии, простейшие, вирусы, грибки и паразиты) также являются одной из приоритетных целей фармацевтических компаний, о чем свидетельствует значительная доля одобрения препаратов с подобным действием. По «поводам регистрации» основная доля приходилась на оригинальные препараты; вклад новых комбинаций и лекарственных форм был максимальным в середине периода и затем снижался. В связи с прекращением действия патентной защиты на многие препараты и накоплений данных об их эффектах в постмаркетинговом периоде можно закономерно отметить постепенный рост числа репозиционирований и расширений показаний.

Ключевые слова: FDA; АТХ; таргетная терапия; тенденции лекарственного дизайна; одобренные лекарственные препараты; новые лекарственные препараты

Список сокращений: ГСК — гемопоэтические стволовые клетки; ЖКТ — желудочно-кишечный тракт; иДПП4 — ингибитор дипептидилпептидазы 4 типа; иНГЛТ2 — ингибитор натрий-глюкозного контранспортёра 2 типа; ЛГ — лютеинизирующий гормон; мРНК — матричная рибонуклеиновая кислота; НМРЛ — немелкоклеточный рак лёгкого; СД — сахарный диабет; СД1 — сахарный диабет первого типа; СД2 — сахарный диабет второго типа; СМА — спинальная мышечная атрофия; ФСГ — фолликулостимулирующий гормон; ХОБЛ — хроническая обструктивная болезнь лёгких; ЦМВ — цитомегаловирус; ЦНС — центральная нервная система; CD — кластер дифференцировки (Cluster of differentiation); CGRP — пептид, связанный с геном кальцитонина; FDA — управление по санитарному надзору за качеством пищевых продуктов и медикаментов (Food and drug administration); IFN — интерферон; IL — интерлейкин (Interleukin); mAb — моноклональное антитело; siRNA — малая интерферирующая рибонуклеиновая кислота; VEGF — фактор роста эндотелия сосудов.

INTRODUCTION

Modern pharmacotherapy for most diseases differs significantly from the one existed several decades ago. Knowledge and understanding of the disease, achievements of fundamental sciences more and more precisely determine the target for therapeutic intervention, allowing the treatment process to be carried out not only effectively, but also at a level that is as comfortable for the patient. The development of original medicines meets the needs of society, the doctor and the patient, offering a new means for treating the disease, while the development of a new dosage form of the original drug, the creation of a generic drug or the inclusion of the active substance

ОБЗОР
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in the composition of a combined drug is aimed more at increasing the convenience and satisfaction of the patient [1, 2]. The expansion of scientific knowledge and technical capabilities of humans determines the evolution of pharmacotherapy for almost every known disease. The processes that make up the life cycle of a medicinal product are extremely diverse, but they are united by characteristics such as innovation, high quality standards, cost and complex formal regulation [3–5].

Strategies for creating new drugs have not changed significantly over the past few decades. Pharmaceutical developments are still represented by both original drugs and their copies, various combinations, as well as new dosage forms of already known active substances, including those in relation to which the so-called repositioning occurred, as a result of which the prospect of use in diseases different from the original goals of molecule development was established. It should be noted that the qualitative level of the developed products has changed significantly, since there is a noticeable trend of pharmaceutical companies investing in the search for and satisfaction of patients' needs in terms of the convenience of drug therapy [6–8].

The development of medicinal products is a risky, lengthy and costly process at all stages of the life cycle, since investments in the creating product do not stop almost until it is completely withdrawn from the market, which happens quite rarely [9, 10]. If we focus directly on the process of developing an original medicinal product, then, with some assumptions, it can be divided into the search for and justification of a target for therapeutic intervention, the selection of the best compound from a number of compounds in terms of its ability to affect the therapeutic target, optimization of the characteristics of the selected compound and the study of its pharmacodynamic, pharmacokinetic and toxicokinetic properties, the implementation of registration studies, registration and obtaining post-registration data [9, 11, 12]. It is important to note that the time, labor and financial costs are most significant up to the registration of the medicinal product, however, the information obtained at the post-registration stage, that is, during the sales period, is fundamental for future developments or modernization of existing ones. It is the analysis of various aspects of drug circulation that allows us to identify patient needs and societal demands, which determines the prospect, indicates the direction of the market and the beacons of successful implementation of new products for developers [5, 13]. Considering that the development of an original medical product requires an ever-increasing amount of resources every year and, as a rule, the original medicinal product to a greater extent meets the criteria of the needs of the doctor and society, the creation of generic drugs, new dosage forms, combinations, delivery systems, etc., requires significantly fewer resources, since these areas are more focused on the patient's needs [7, 8, 14].

The pharmaceutical industry is certainly an important component of the state's economy and the most attractive in terms of investment. Acting as the main beneficiary of the results of fundamental sciences and the main driver of their applied function, pharmacy demonstrates significant progress in the treatment of diseases that were previously considered incurable. It is important to note that modern pharmacy is increasingly using a patient-centric paradigm in drug development, presenting patients with drugs in new dosage forms, combinations, doses and methods of delivery. The proportion of drugs created by biotechnological means continues to increase. The segment of orphan medicines is also gradually increasing [15–17].

The presented data are of interest, indicating trends in drug development and demonstrating the ability of modern pharmaceutical companies to offer sometimes "revolutionary" solutions to previously unsolvable problems of medical and preventive services [18–20].

Global analytics and monitoring of the pharmaceutical market allow us to determine the current situation and vectors of development, as well as problems with current developments or products, which is a source of valuable information for healthcare, pharmaceutical marketing and industry purposes.

The presented work reflects the history of approvals by the Food and Drug Administration (FDA) of medicinal products manufactured by foreign pharmaceutical companies, including leaders in the pharmaceutical market.

THE AIM. To identify and describe the key characteristics of medicinal products approved by the Food and Drug Administration (FDA) and

released by foreign pharmaceutical companies for the period 2012–2024.

MATERIALS AND METHODS

Data for the analysis were collected from official sources, taking into account all medicinal products approved by the FDA for the period from 2012 to 2024. The drugs were systematized by year, route and reason for approval, the nature of the active substance (synthetic, semi-synthetic, natural or biological) and the target disease (indication for use) in accordance with the codes of the anatomical-therapeutic-chemical classification (ATC). The following approval routes are highlighted: original medicinal product, generic medicinal product (generic), new dosage form, new combination, new use, new manufacturer, re-registration.

The term "Biosimilar medicinal product" (biosimilar, biosimilar medicinal product, biosimilar) meant a biological medicinal product that contains a version of the active substance of the registered biological original (reference) product and for which similarity (similarity) has been demonstrated on the basis of comparative studies with the reference product in terms of quality, biological activity, efficacy and safety.

The term "Generic medicinal product" (generic) meant a medicinal product that has the same quantitative and qualitative composition of active substances and the same dosage form as the original product, and whose bioequivalence to the original medicinal product is confirmed by appropriate bioavailability studies. Different salts, esters, isomers, mixtures of isomers, complexes or derivatives of the active substance are recognized as the same active substance if their safety and efficacy do not differ significantly. Different oral dosage forms with immediate release are recognized as the same dosage form within the framework of bioavailability studies.

Also, the category "Generic drug" (exclusively within the framework of this article, for ease of perception of information) conditionally included a hybrid medicinal product — a medicinal product that does not fall under the definition of a generic medicinal product when it is impossible to confirm its bioequivalence using bioavailability studies, as well as if changes have occurred in this drug active substance (substances), indications for use, dosage, dosage form or route of administration compared to the original drug.

The drugs were divided by areas of application in accordance with the codes of the anatomical-therapeutic-chemical classification (ATC):

- Code A: Alimentary tract and metabolism;
- Code B: Blood and Blood Forming Organs;
- Code C: Cardiovascular System;
- Code D: Dermatologicals;
- Code G: Genito Urinary System and Sex Hormones;
- Code H: Systemic Hormonal Preparations, excl. Sex Hormones and Insulins;
- Code J: Antiinfectives for Systemic Use;
- Code L: Antineoplastic and Immunomodulating Agents;
- Code M: Musculo-Skeletal System;
- Code N: Nervous System;
- Code P: Antiparasitic Products, Insecticides and Repellents;
- Code R: Respiratory System;
- Code S: Sensory Organs;
- Code V: Various.

Data on the indications of medicinal products, as well as information on the mechanism of action, were taken from the published summary of product characteristics (SmPC) published on the Drugs.com website. Drugs.com reports were also used to describe previously registered medicinal products for which a new indication is presented. The search for literature data on fundamental studies concerning the mechanisms of action of the presented medicinal products was carried out in the PubMed, ResearchGate, Google Scholar and elibrary.ru databases.

For systematization, calculation of proportions and trends, as well as visualization of the obtained results, the R software package was used: R version 4.5.1 (2025-06-13 ucrt), ggplot2 version 3.5.2, RStudio 2025.05.1 Build 513.

RESULTS

When analyzing the approval history, the total number of approvals, approvals of new molecules, combinations, dosage forms and/or indications for use, as well as reproduced drugs were taken into account; changes in the manufacturer or re-registration were taken into account in the "other" category (not presented in the text description).

ОБЗОР
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2012

In 2012, 65 drugs were approved. Among them there were 27 new original molecules. As previously, except for 2016, the largest share was accounted for by antitumor drugs and immunomodulators (class L). For 14 drugs, the approval was associated with a change of manufacturer and for 5, re-registration was carried out. 11 new combinations and 9 new dosage forms were registered. A new indication was added for 6 drugs. The distribution by ATC classes and chemical type is presented in Figure 1.

Vismodegib (Erivedge®) is approved for the treatment of metastatic basal cell carcinoma or this disease in the late stages. It acts through the Hedgehog signaling pathway: selectively inhibits the Smoothened protein, which suppresses the pathological activation of the Hedgehog signal, characteristic of some basal cell carcinomas[1]

Glucarpidase (Voraxaze®) is an enzyme (carboxypeptidase) that converts methotrexate into inactive metabolites, reducing its plasma concentration. It is used as a means to treat methotrexate overdose, leading to renal failure and subsequent reduction of its clearance[2].

A strong opioid agonist — fentanyl (Subsys) — in the form of a spray for sublingual administration for accelerated absorption has been approved. It is used to relieve episodes of intractable pain in patients with tumors receiving opioid treatment and resistant to them[3].

Taliglucerase alfa (Elelyso®) is recombinant human glucocerebrosidase for enzyme replacement therapy for Gaucher disease has been approved. The enzyme complements the insufficient lysosomal activity, promoting the breakdown of accumulated glucosylceramide. Elelyso® (finished product of taliglucerase alfa) is produced using plant cell culture (expression system in carrot cells) - this is the first FDA-approved drug produced using the plant ProCellEx® platform[4].

A radiopharmaceutical drug containing florbetapir F-18 (Amyvid®) as an active substance has been approved. It is used in positron emission tomography to visualize β-amyloid in the brain. The diagnostic procedure helps in assessing the presence of dense amyloid plaques associated with Alzheimer's disease[5].

A gel for topical use based on ingenol mebutate (Picato®) has been created. The active substance combines a direct cytolytic effect on affected keratinocytes and promotes an inflammatory response at the site of the lesion, which is used to treat actinic keratoses[6].

In 2012, a pegylated peptide peginesatide (Omontys®) was developed, which is an agonist of the erythropoietin receptor. The drug based on it was planned to be used to stimulate erythropoiesis in patients with anemia caused by dialysis for chronic kidney disease. It is noteworthy that despite the approval, in 2013 this drug was discontinued and a recall of all released series was announced, since the PEARL study revealed that the drug was inferior to the reference drugs (darbepoetin alfa) in terms of safety in relation to the cardiovascular system.

2013

In 2013, the FDA approved 73 drugs, 28 of which were represented by new molecules (including 10 molecules of biological origin), 11 were new combinations of drugs; in 15 drugs had a new dosage form or a new indication for use. The distribution by ATC classes and chemical type is presented in Figure 2.

Examples of drugs that have been approved: ceritinib (Zykadia®; a drug for the treatment of inoperable or metastatic non-small cell lung cancer [NSCLC] with a specific mutation)[7] tisagenlecleucel (Kymriah®; the first gene therapy approved for the treatment of acute lymphoblastic leukemia in children and young people)[8], nivolumab (Opdivo®; a drug for the treatment of various types of cancer, including melanoma and lung cancer), durvalumab (Imfinzi®; approved for the treatment of lung cancer, in particular, for patients with locally advanced disease not amenable to surgical intervention)[9], Entresto® (sacubitril + valsartan; a combined drug for the treatment of chronic heart failure)[10].

[1] Drugs.com. Erivedge. Avavilable from: https://www.drugs.com/erivedge.html
[2] Drugs.com. Voraxaze. Avavilable from: https://www.drugs.com/voraxaze.html
[3] Drugs.com. Subsys. Avavilable from: https://www.drugs.com/subsys.html
[4] Drugs.com. Elelyso. Avavilable from: https://www.drugs.com/elelyso.html
[5] Drugs.com. Amyvid. Avavilable from: https://www.drugs.com/amyvid.html
[6] Drugs.com. Picato Gel. Avavilable from: https://www.drugs.com/picato.html
[7] Drugs.com. Zykadia. Avavilable from: https://www.drugs.com/zykadia.html
[8] Drugs.com. Kymriah. Avavilable from: https://www.drugs.com/kymriah.html
[9] Drugs.com. Imfinzi. Avavilable from: https://www.drugs.com/imfinzi.html
[10] Drugs.com. Entresto. Avavilable from: https://www.drugs.com/entresto.html

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The pomalidomide (Pomalyst®) is approved as a new antitumor agent[11]. This is a derivative of thalidomide[12] is a representative of the next generation of immunomodulators after lenalidomide, its peculiarity lies in the ability to inhibit both tumor cells and vascular compartments of myeloma cancer [21].

The approval of canagliflozin (Invokana®), the second, but far from the last, approved gliflozin not only for the treatment of T2DM, but also for the prevention of its cardiovascular complications, deserves special attention[13].

Riociguat (Adempas®) is the first-in-class soluble guanylate cyclase stimulator for the treatment of chronic thromboembolic pulmonary hypertension and pulmonary arterial hypertension[14]. The second approved drug macitentan (Opsumit®) for the treatment of the same disease is an antagonist of two subtypes of endothelin receptors A and B[15]. The third drug for the treatment of arterial hypertension is treprostinil (Orenitram®) — an artificial prostacyclin that causes vasodilation in the lungs[16].

The NS3/4A protease inhibitor simeprevir (Olysio™)[17] and the hepatitis C virus NS5B protein inhibitor sofosbuvir (Sovaldi)[18] are the first two drugs in the class for the treatment of hepatitis C.

For the treatment of homozygous familial hypercholesterolemia, the second-generation antisense oligonucleotide mipomersen (Kynamro™)[19] has been approved, which binds to messenger RNA encoding apolipoprotein B-100, its formula is resistant to nucleases and therefore it can be administered to the patient weekly [22].

2014

In 2014, 92 drugs received FDA approval, 46 of which were original molecules (including 15 of biological origin), and 15 were new combinations; 15 drugs had a new dosage form or a new indication for use (Fig. 3).

The trametinib (Mekinist®) and dabrafenib (Tafinlar®) received accelerated approval for combination therapy of melanoma[20]. Examples of approved drugs were glatiramer acetate (Copaxone®; approval of a three-times-a-week dosing regimen of 40 mg/mL for the treatment of multiple sclerosis)[21], ecallantide (Kalbitor®; approval of expanded use for the treatment of hereditary angioedema in patients aged 12 years and older)[22], dabigatran etexilate mesylate (Pradaxa®; approval for the treatment of deep vein thrombosis and pulmonary embolism)[23], panitumumab (Vectibix®; approval of first-line use in combination with FOLFOX for patients with metastatic colorectal cancer of the wild type KRAS)[24], human immunoglobulin (Octagam® 10%; approval for the treatment of chronic immune thrombocytopenic purpura)[25], tiotropium bromide (Spiriva® Respimat®; approval for maintenance treatment of COPD)[26], adalimumab (Humira®; approval for the treatment of Crohn's disease in pediatric patients)[27], ramucirumab (Cyramza®; approval in combination with paclitaxel for the treatment of late-stage gastric adenocarcinoma after previous

[11] Drugs.com. Pomalyst. Avavilable from: https://www.drugs.com/pomalyst.html
[12] DrugBank.com. Thalidomide. Avavilable from: https://go.drugbank.com/drugs/DB01041
[13] Drugs.com. Invokana. Avavilable from: https://www.drugs.com/invokana.html
[14] Drugs.com. Adempas. Avavilable from: https://www.drugs.com/adempas.html
[15] Drugs.com. Opsumit. Avavilable from: https://www.drugs.com/opsumit.html
[16] Drugs.com. Orenitram. Avavilable from: https://www.drugs.com/orenitram.html
[17] Drugs.com. Olysio. Avavilable from: https://www.drugs.com/olysio.html
[18] Drugs.com. Sovaldi. Avavilable from: https://www.drugs.com/sovaldi.html
[19] Drugs.com. Kynamro. Avavilable from: https://www.drugs.com/kynamro.html
[20] Drugs.com. GSK Gains Accelerated FDA Approval for Combination Use of Mekinist (trametinib) and Tafinlar (dabrafenib). Avavilable from: https://www.drugs.com/ newdrugs/gsk-gains-accelerated-fda-approval-combination-mekinist-trametinib-tafinlar-dabrafenib-4003.html
[21] Drugs.com. Copaxone. Avavilable from: https://www.drugs.com/copaxone.html
[22] Drugs.com. FDA Approves Expanded Use of Kalbitor for the Treatment of HAE to Patients 12 Years of Age and Older. Avavilable from: https://www.drugs.com/ newdrugs/fda-approves-expanded-kalbitor-hae-patients-12-years-age-older-4029.html
[23] Drugs.com. FDA Approves Pradaxa for Deep Venous Thrombosis and Pulmonary Embolism. Avavilable from: https://www.drugs.com/newdrugs/fda-approves-pradaxa-deep-venous-thrombosis-pulmonary-embolism-4030.html
[24] Drugs.com. FDA Approves First-Line Use of Vectibix (panitumumab) Plus FOLFOX for Patients with Wild-Type KRAS Metastatic Colorectal Cancer. Avavilable from: https://www. drugs.com/newdrugs/fda-approves-first-line-vectibix-panitumumab-plus-folfox-patients-wild-type-kras-metastatic-4558.html
[25] Drugs.com. Octapharma USA Announces FDA Approval of Octagam 10% for the treatment of Chronic Immune Thrombocytopenic Purpura (ITP). Avavilable from: https:// www.drugs.com/newdrugs/octapharma-usa-announces-fda-approval-octagam-10-chronic-immune-thrombocytopenic-purpura-itp-5601.html
[26] Drugs.com. FDA Approves Spiriva Respimat. Avavilable from: https://www.drugs.com/newdrugs/fda-approves-spiriva-respimat-tiotropium-maintenance-copd-4088.html
[27] Drugs.com. FDA Approves Humira (adalimumab) for the Treatment of Pediatric Patients with Crohn's Disease. Avavilable from: https://www.drugs.com/newdrugs/fda-approves-humira-adalimumab-pediatric-patients-crohn-s-4091.html

ОБЗОР
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chemotherapy)[28], simeprevir (Olysio™; approval in combination with sofosbuvir for the treatment of chronic hepatitis C genotype 1)[29].

Gliflozins — dapagliflozin (Farxiga®)[30] and empagliflozin (Jardiance®)[31], — as well as GLP-1 agonists albiglutide (Tanzeum™)[32] and dulaglutide (Trulicity®)[33] are approved for the treatment of T2DM and concomitant pathologies (heart failure, CKD or reduction of the risk of CVDs).

L-threo-dihydroxyphenylserine (L-DOPS, Droxidopa) was first described in 1971 [23], but approved for the treatment of hypotension only in 2014 (Northera®). L-DOPS is a synthetic amino acid precursor that acts as a prodrug to the neurotransmitter norepinephrine (noradrenaline), acts as a non-selective α- and β-adrenergic receptor agonist, increases norepinephrine levels in the peripheral nervous system[34]. For the treatment of lipodystrophy in 2014, a synthetic leptin analogue — metreleptin (Myalept®) was approved, the use of which reduces blood glucose and body weight[35]. Dantrolene sodium (Ryanodex®) is a postsynaptic muscle relaxant (inhibits the release of Ca^{2+} ions from sarcoplasmic reticulum stores by antagonizing ryanodine receptors), a hydantoin derivative, but unlike phenytoin, it does not exhibit antiepileptic activity, it is approved for the treatment of malignant hyperthermia[36]. For the treatment of insomnia, the first orexin receptor antagonist (lemborexant, Dayvigo®; approved in 2019)[37] and daridorexant, Quviviq®; approved in 2022)[38] — suvorexant (Belsomra®)[39] — acts as a selective dual antagonist of orexin receptors 1 and 2.

For the treatment of opioid-induced constipation, a polyethylene glycol-modified α-naloxol derivative — naloxegol (Movantik®)[40] has been approved, which inhibits the binding of opioids to μ-opioid receptors in the gastrointestinal tract (GIT), thereby preventing slowing of passage, hypertonus and increased fluid reabsorption in the GIT [24].

The first-in-class drug for the treatment of idiopathic pulmonary fibrosis is pirfenidone (Esbriet®) has been approved, which acts by reducing the production of growth factors and procollagens I and II[41].

For the treatment of acromegaly (previously, in 2012, approved for the treatment of Cushing's disease), pasireotide (Signifor®)[42] has been approved — this is a somatostatin analogue, which has a 40-fold higher affinity for somatostatin receptor 5. Ivermectin (Soolantra®) was described in 1975 [25], for its discovery Satoshi Omura (Kitasato University) and William Campbell (Merck) received half of the Nobel Prize in 2015. This substance is widely used as an antiparasitic agent, and in 2014 it was approved for the treatment of rosacea. The drug binds to glutamate-gated chloride channels, opening them increases the flow of chloride ions, which leads to hyperpolarization of the cell membranes of parasites, including *Demodex folliculorum* mites[43]. Avermectin group drugs stimulate the release of γ-aminobutyric acid (GABA) from nerve endings and increase the affinity of GABA to receptor sites on the postsynaptic membrane of muscle cells, which blocks the transmission of nerve impulses [26].

Liraglutide (Saxenda®) (approved in 2010) was approved in 2014 for use in obesity[44], which on the one hand is another successful example of adapting the undesirable effects of a drug for medical purposes, and on the other hand opens up the potential for a multiple expansion of prescriptions for drugs with similar effects.

[28] Drugs.com. FDA Approves Cyramza (ramucirumab) in Combination with Paclitaxel for Advanced Gastric Cancer after Prior Chemotherapy. Avavilable from: https://www.drugs. com/newdrugs/fda-approves-cyramza-ramucirumab-combination-paclitaxel-advanced-gastric-cancer-after-prior-4106.html

[29] Drugs.com. FDA Approves Olysio (simeprevir) in Combination with Sofosbuvir for Genotype 1 Chronic Hepatitis C Infection. Avavilable from: https://www.drugs.com/ newdrugs/fda-approves-olysio-simeprevir-combination-sofosbuvir-genotype-1-chronic-hepatitis-c-infection-4107.html

[30] Drugs.com. Farxiga. Avavilable from: https://www.drugs.com/farxiga.html

[31] Drugs.com. Jardiance. Avavilable from: https://www.drugs.com/jardiance.html

[32] Drugs.com. Tanzeum. Avavilable from: https://www.drugs.com/tanzeum.html

[33] Drugs.com. Trulicity. Avavilable from: https://www.drugs.com/trulicity.html

[34] Drugs.com. Northera. Avavilable from: https://www.drugs.com/northera.html

[35] Drugs.com. Myalept. Avavilable from: https://www.drugs.com/myalept.html

[36] Drugs.com. FDA Approves Ryanodex. Avavilable from: https://www.drugs.com/newdrugs/fda-approves-ryanodex-malignant-hyperthermia-4058.html

[37] Drugs.com. Dayvigo. Avavilable from: https://www.drugs.com/dayvigo.html

[38] Drugs.com. Quviviq. Avavilable from: https://www.drugs.com/quviviq.html

[39] Drugs.com. Belsomra. Avavilable from: https://www.drugs.com/belsomra.html

[40] Drugs.com. Movantik. Avavilable from: https://www.drugs.com/movantik.html

[41] Drugs.com. Esbriet. Avavilable from: https://www.drugs.com/esbriet.html

[42] Drugs.com. Signifor. Avavilable from: https://www.drugs.com/signifor.html

[43] Drugs.com. Soolantra. Avavilable from: https://www.drugs.com/soolantra.html

[44] Drugs.com. Saxenda. Avavilable from: https://www.drugs.com/saxenda.html

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2015

In 2015, 99 drugs were registered in the USA, including 41 original drugs (including 21 biologicals), 20 new combinations, only 1 generic drug glatiramer acetate (Copaxone®)[45] and 1 drug with a new indication for use. In particular, deferasirox (Jadenu®; a new form of iron chelating drug that simplifies the treatment of patients with chronic iron overload)[46], esomeprazole magnesium (Nexium® 24HR; an over-the-counter version of the drug for the treatment of acid reflux)[47], levetiracetam (Spritam®; the first 3D-printed drug for the treatment of epilepsy)[48], lobelia and ivacaftor (Orkambi®; a combination drug for the treatment of cystic fibrosis)[49], palbociclib (Ibrance®; a drug for the treatment of breast cancer)[50], ceritinib (Zykadia®; for the treatment of metastatic NSCLC)[51], venetoclax (Venclexta®; for the treatment of chronic lymphocytic leukemia)[52], eliglustat (Cerdelga®; for the treatment of Gaucher's disease)[53], cariprazine (Vraylar®; for the treatment of schizophrenia and bipolar disorder)[54], lenvatinib (Lenvima®; for the treatment of thyroid cancer)[55] were approved (Fig. 4).

The approval history began with the new drug edoxaban (Savaysa®; an anticoagulant, a direct factor Xa inhibitor) for the prevention of stroke and systemic embolism[56]. Solution for renal replacement therapy (Phoxillum®) approved as a means for dialysis[57].

The synthesis of eluxadoline (μ- and κ-opioid receptor agonist and δ-opioid receptor antagonist in the enteric nervous system) was first described in 2006, but it was approved only 9 years later for clinical use in the treatment of diarrhea and abdominal pain in people with irritable bowel syndrome with a predominance of diarrhea (Viberzi®)[58]. The first in the class of NS5A inhibitors daclatasvir (Daklinza®)[59] was approved in 2015, developed by scientists from Bristol Myers Squibb and indicated for the treatment of hepatitis C also for the treatment of this disease the drug Technivie™ was approved, consisting of three active components: ombitasvir (NS5A inhibitor), paritaprevir (acylsulfonamide inhibitor of NS3-4A serine protease), ritonavir (enhances the effects of other protease inhibitors)[60]. Of particular note is the approval of dichlorphenamide (Keveyis®) for the treatment of primary hypokalemic and hyperkalemic periodic paralysis[61]; the effectiveness of the drug against glaucoma has been known since 1958 [27], and epilepsy since 1978 [28]. Flibanserin (Addyi®) was originally developed as an antidepressant (predominantly activates 5-HT1A receptors in the prefrontal cortex, increases dopamine and norepinephrine levels, and reduces serotonin levels), but was approved as a drug for the treatment of women in premenopause with hypolibidemia[62].

As an antiemetic (during chemotherapy), a selective neurokinin-1 receptor (NK1 receptor) antagonist, rolapitant (Varubi™), was approved, originally developed by Schering-Plough®, information about the effects is available since 2006[63].

Cariprazine (Vraylar®)[64] is an atypical neuroleptic from Gedeon Richter® Company, which acts as a partial agonist of D3R (highly selective), D2R dopamine receptors and 5-HT1A serotonin receptors, and as an antagonist of 5-HT2B and 5-HT2A receptors. In 2022, the drug was approved as an adjunct for major depressive disorder. Brexpiprazole (Rexulti®) is approved for the treatment of Schizophrenia and major depressive disorder, is a derivative of

[45] Drugs.com. Glatopa (injection). Avavilable from: https://www.drugs.com/mtm/glatopa-injection.html
[46] Drugs.com. Jadenu. Avavilable from: https://www.drugs.com/jadenu.html
[47] Drugs.com. Nexium. Avavilable from: https://www.drugs.com/nexium.html
[48] Drugs.com. Spritam. Avavilable from: https://www.drugs.com/spritam.html
[49] Drugs.com. Orkambi. Avavilable from: https://www.drugs.com/orkambi.html
[50] Drugs.com. Ibrance. Avavilable from: https://www.drugs.com/ibrance.html
[51] Drugs.com. Zykadia. Avavilable from: https://www.drugs.com/zykadia.html
[52] Drugs.com. Venclexta. Avavilable from: https://www.drugs.com/venclexta.html
[53] Drugs.com. Cerdelga. Avavilable from: https://www.drugs.com/cerdelga.html
[54] Drugs.com. Vraylar. Avavilable from: https://www.drugs.com/vraylar.html
[55] Drugs.com. Lenvima. Avavilable from: https://www.drugs.com/lenvima.html
[56] Drugs.com. Savaysa. Available from: https://www.drugs.com/savaysa.html
[57] Drugs.com. Phoxillum. Available from: https://www.drugs.com/pro/phoxillum.html
[58] Drugs.com. Viberzi. Available from: https://www.drugs.com/viberzi.html
[59] Drugs.com. Daklinza. Available from: https://www.drugs.com/daklinza.html
[60] Drugs.com. Technivie. Available from: https://www.drugs.com/technivie.html
[61] Drugs.com. Keveyis. Available from: https://www.drugs.com/mtm/keveyis.html
[62] Drugs.com. Addyi. Available from: https://www.drugs.com/addyi.html
[63] Drugs.com. Varubi. Available from: https://www.drugs.com/varubi.html
[64] Drugs.com. Vraylar. Available from: https://www.drugs.com/vraylar.html

ОБЗОР
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aripiprazole (aripiprazole lauroxil is an N-acyloxymethyl prodrug of aripiprazole, which is administered intramuscularly once every 4–8 weeks for the treatment of Schizophrenia; approved in 2015), like the previous drug, it is a partial agonist of serotonin 5-HT1A and dopamine D2R and D3R receptors. The generic was approved in 2022 and since 2023 it can be used to relieve agitation in Alzheimer's disease[65].

Olopatadine (Pazeo®)[66] is a selective histamine H1 receptor antagonist, patented in 1986, its use in the clinic began in 1997, in 2015 it was approved as an ophthalmic solution for allergic conjunctivitis, since 2020 it has been available over-the-counter in the USA.

Asfotase alfa (Strensiq®) is a drug for enzyme replacement therapy, a recombinant glycoprotein with the catalytic domain of tissue-specific alkaline phosphatase, a genetic defect in which causes hypophosphatasia[67]. Another drug for enzyme replacement therapy in the form of a solution for intravenous infusions is sebelipase alfa (Kanuma™) — recombinant lysosomal acid lipase[68].

The antidote sugammadex (Bridion®) is the first in class substance that selectively binds relaxant to reverse neuromuscular blockade caused by rocuronium and vecuronium during general anesthesia and, compared to other reversal agents, potentially has fewer side effects[69].

Lesinurad (Zurampic®) inhibits URAT1 (a protein that is responsible for the reabsorption of uric acid in the kidneys) and OAT4 (associated with diuretic-induced hyperuricemia)[70].

Selexipag (Uptravi®) and its active metabolite ACT-333679 act on the prostacyclin receptor in the lungs, which leads to vasodilation of arteries, reduced cell proliferation and inhibition of platelet aggregation; approved for the treatment of pulmonary hypertension[71].

For the treatment of HIV in 2015, 4 new combination drugs were approved — Evotaz® (atazanavir [HIV protease inhibitor] and cobicistat [cytochrome P450 enzyme inhibitor])[72], Prezcobix® (cobicistat and darunavir [HIV protease inhibitor])[73], Dutrebis® (lamivudine [HIV nucleoside reverse transcriptase inhibitor] and raltegravir [approved since 2007; HIV integrase inhibitor])[74], Stribild® (cobicistat, elvitegravir [approved since 2014; HIV integrase inhibitor], emtricitabine [approved since 2003; synthetic nucleoside analog of cytidine, HIV nucleoside reverse transcriptase inhibitor] and tenofovir alafenamide [tenofovir prodrug, nucleotide reverse transcriptase inhibitor])[75].

In the field of diabetes treatment, three combination drugs were approved in 2015 — Glyxambi® (empagliflozin [SGLT2i] and linagliptin [DPP4i])[76], Synjardy® (empagliflozin [SGLT2i] and metformin)[77], Ryzodeg® 70/30 (insulin degludec [long-acting] and insulin aspart [rapid-acting]); two drugs containing insulin glargine were approved in a new dosage form (more concentrated solution)[78]; Tresiba® (insulin degludec) — basal insulin with ultra-long action (over 24 hours)[79].

2016

In 2016, only 69 drugs were approved, of which 24 were original (including 13 biologicals), 13 were new combinations, 2 were generic drugs, and 18 had a new dosage form or a new indication for use. 2016 is the only year in the studied period in which class L drugs were not the predominant group: that year, 13 antimicrobial drugs for systemic action (class J) were also registered (Fig. 5).

In particular, nusinersen (Spinraza®; for the treatment of spinal muscular atrophy in children and

[65] Drugs.com. Rexulti. Available from: https://www.drugs.com/rexulti.html
[66] Drugs.com. Pazeo. Available from: https://www.drugs.com/mtm/pazeo.html
[67] Drugs.com. Strensiq. Available from: https://www.drugs.com/strensiq.html
[68] Drugs.com. Kanuma. Available from: https://www.drugs.com/mtm/kanuma.html
[69] Drugs.com. Bridion. Available from: https://www.drugs.com/mtm/bridion.html
[70] Drugs.com. Zurampic. Available from: https://www.drugs.com/zurampic.html
[71] Drugs.com. Uptravi. Available from: https://www.drugs.com/uptravi.html
[72] Drugs.com. Evotaz. Available from: https://www.drugs.com/evotaz.html
[73] Drugs.com. Prezcobix. Available from: https://www.drugs.com/prezcobix.html
[74] Drugs.com. Dutrebis. Available from: https://www.drugs.com/history/dutrebis.html
75 Drugs.com. Stribild. Available from: https://www.drugs.com/stribild.html
[76] Drugs.com. Glyxambi. Available from: https://www.drugs.com/glyxambi.html
[77] Drugs.com. Synjardy Available from: https://www.drugs.com/synjardy.html
[78] Drugs.com. Ryzodeg FlexTouch Pen. Available from: https://www.drugs.com/ryzodeg-70-30.html
[79] Drugs.com. Tresiba. Available from: https://www.drugs.com/tresiba.html

adults)[80], rucaparib (Rubraca®; for the treatment of a certain type of ovarian cancer in women[81], crisaborole (Eucrisa®; for the treatment of mild to moderate eczema [atopic dermatitis] in patients over 2 years of age)[82], bezlotoxumab (Zinplava®; to reduce the risk of recurrence of infection caused by *Clostridium difficile* in patients over 18 years of age)[83], olaratumab (Lartruvo®; for the treatment of adults with certain types of soft tissue sarcoma)[84], Exondys 51® (eteplirsen; for the treatment of patients with Duchenne muscular dystrophy)[85], Adlyxin® (lixisenatide; to improve glycemic control)[86], Xiidra® (lifitegrast; for the treatment of signs and symptoms of dry eye syndrome)[87], Epclusa® (sofosbuvir+velpatasvir; for the treatment of all six major forms of the hepatitis C virus)[88] were approved.

Pimavanserin (Nuplazid™) is a selective inverse agonist of the serotonin 5-HT2A receptor and significantly less active against 5-HT2C; received breakthrough antipsychotic therapy status in 2014, was approved in 2016 for the treatment of hallucinations and delusions in Parkinson's disease, and in 2018 it became available in new dosage forms[89].

Brivaracetam (Briviact®) is chemically similar to levetiracetam, which has anticonvulsant (antiepileptic) properties by binding to synaptic vesicle glycoprotein 2A, approved for the relief of epileptic seizures[90].

Defibrotide (Defitelio®) is a mixture of single-stranded oligonucleotides purified from the intestinal mucosa of pigs; polydeoxyribonucleotide sodium salt; approved for the treatment of hepatic veno-occlusive disease in people who have undergone bone marrow transplantation, acts as an endothelial protector, enhances the function of tissue-type plasminogen activator (tPA) and promotes plasminogen activation-1 (PAI-1)[91].

Obeticholic acid (Ocaliva®)[92] is a semi-synthetic bile acid analogue, chemically 6α-ethyl-chenodeoxycholic acid, a farnesoid X receptor agonist, approved for the treatment of primary biliary cholangitis. The prototype of this compound, chenodeoxycholic acid, was identified in 1999.

Lifitegrast (Xiidra®) inhibits integrin, lymphocyte function-associated antigen 1 (LFA-1), from binding to intercellular adhesion molecule 1 (ICAM-1). This mechanism suppresses T-lymphocyte-mediated inflammation. It is used to treat dry eye symptoms[93].

Phentermine hydrochloride (phenyl-tertiarybutyl amine) (Qsymia®) is a TAAR1 agonist (like amphetamine, which was approved in early 2016 for the treatment of attention deficit hyperactivity disorder), enhances the release of norepinephrine (to a greater extent), dopamine and serotonin (to a lesser extent) in neurons, blunts hunger, enhances fat catabolism (by stimulating peripheral secretion of norepinephrine and epinephrine)[94]. It was first used to suppress appetite in 1959.

Eteplirsen (Exondys 51®) is a morpholino antisense oligomer that triggers exon 51 skipping during pre-mRNA splicing of the dystrophin RNA transcript, which alters the downstream reading frame of dystrophin; eteplirsen administration to patients with specific nonsense mutations causing Duchenne muscular dystrophy[95]. Eteplirsen restores the reading frame of dystrophin mRNA and leads to the production of functional (albeit modified due to the presence of an internal deletion consisting of both the patient's original defect and the therapeutically altered dystrophin protein) dystrophin protein [29]. The second antisense oligonucleotide nusinersen (Spinraza®) is the first approved drug for the treatment of spinal muscular atrophy, which is caused by mutations in the *SMN1* gene, which encodes the survival motor neuron protein. Nusinersen modulates alternative splicing of the *SMN2* gene, functionally converting it into

[80] Drugs.com. Spinraza. Available from: https://www.drugs.com/spinraza.html
[81] Drugs.com. Rubraca. Available from: https://www.drugs.com/rubraca.html
[82] Drugs.com. Eucrisa. Available from: https://www.drugs.com/eucrisa.html
[83] Drugs.com. Zinplava. Available from: https://www.drugs.com/zinplava.html
[84] Drugs.com. Lartruvo: Package Insert / Prescribing Info. Available from: https://www.drugs.com/ pro/lartruvo.html
[85] Drugs.com. Exondys 51. Available from: https://www.drugs.com/exondys-51.html
[86] Drugs.com. Adlyxin. Available from: https://www.drugs.com/adlyxin.htm
[87] Drugs.com. Xiidra. Available from: https://www.drugs.com/xiidra.html
[88] Drugs.com. Epclusa. Available from: https://www.drugs.com/epclusa.html
[89] Drugs.com. Nuplazid. Available from: https://www.drugs.com/nuplazid.html
[90] Drugs.com. Briviact. Available from: https://www.drugs.com/briviact.html
[91] Drugs.com. Defitelio. Available from: https://www.drugs.com/mtm/defitelio.html
[92] Drugs.com. Ocaliva. Available from: https://www.drugs.com/ocaliva.html
[93] Drugs.com. Xiidra. Available from: https://www.drugs.com/xiidra.html
[94] Drugs.com. Qsymia. Available from: https://www.drugs.com/qsymia.html
[95] Drugs.com. Exondys 51. Available from: https://www.drugs.com/exondys-51.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

the *SMN1* gene, thereby increasing the level of SMN protein in the central nervous system (CNS) [30].

Crisaborole (Eucrisa®) is a non-steroidal anti-inflammatory drug for topical use in mild to moderate atopic dermatitis (eczema) in adults and children, which acts as an inhibitor of phosphodiesterase 4B (PDE-4B), suppressing the release of tumor necrosis factor α (TNFα), interleukin (IL) 12, IL-23 and other cytokines, proteins that are believed to be involved in the immune response and inflammation[96]. Interestingly, in 2014, a drug containing tavaborole (Kerydin™) was approved, which is structurally similar to crisaborole, but acts as an inhibitor of fungal cell leucyl-tRNA synthetase, blocking protein synthesis and, accordingly, slowing growth; it is used to treat onychomycosis[97].

Oxymetazoline hydrochloride (Kovanaze™) (an imidazoline derivative, a mixed α1 / α2 adrenergic receptor agonist) and tetracaine hydrochloride (a local anesthetic, blocks Na^+ ion channels necessary for the initiation and conduction of neural impulses) are approved in spray form for local anesthesia during dental treatment, which is an alternative to injections[98].

Three drugs were approved for the treatment of diabetes mellitus in 2016: a new form of lixisenatide (Adlyxin™) (aGLP-1)[99], a combination of lixisenatide with insulin glargine (a basal insulin analogue) (Soliqua 100/33)[100], and a combination of insulin degludec (an ultra-long-acting basal insulin analogue) and liraglutide (aGLP-1) (Xultophy®)[101].

Three new combination drugs have been approved for the treatment of chronic hepatitis: Zepatier® (elbasvir [hepatitis C virus NS5A protein inhibitor] and grazoprevir [NS3/4A inhibitor])[102], Epclusa® (sofosbuvir [NS5B polymerase inhibitor] and velpatasvir [NS5A polymerase inhibitor])[103], Viekira® (dasabuvir [NS5B polymerase inhibitor], ombitasvir [NS5A polymerase inhibitor], paritaprevir [NS3-4A serine protease inhibitor] and ritonavir [originally developed as an HIV protease inhibitor])[104] and one new drug: tenofovir alafenamide (Vemlidy®) — a nucleotide reverse transcriptase inhibitor and a prodrug of tenofovir (previously approved for the treatment of HIV)[105].

For the treatment of anorexia, a drug containing dronabinol (Syndros™) is a delta-9-tetrahydrocannabinol, which, in addition to stimulating appetite, has an analgesic effect and is effective for nocturnal apnea, has been approved[106].

In the field of treatment of cardiovascular diseases, the following were approved: ephedrine sulfate (Akovaz®) (treatment of hypotension; new manufacturer)[107], Byvalson™ (a combination of nebivolol [a cardioselective third-generation β-blocker] and valsartan [an angiotensin II receptor blocker])[108], nitroglycerin in a new dosage form for the prevention of angina pectoris (GoNitro™)[109], lisinopril in a new dosage form (Qbrelis®) approved for the treatment of hypertension[110], and aspirin with omeprazole in the form of a new combination (Yosprala®) approved for the prevention of ischemic stroke[111].

2017

In 2017 were approved 103 drugs, including 42 original drugs (from them 27 biologicals), 12 new combinations, 2 reproduced drugs, as well as 27 drugs in a new dosage form or with new indications for use. Examples of approved drugs in 2017 are Zolgensma® (onasemnogene abeparvovec; gene therapy for the treatment of spinal muscular atrophy [SMA]), Kymriah® (tisagenlecleucel; the first CAR-T therapy for the treatment of relapsed acute myeloid leukemia in children and young people), Takhzyro® (lanadelumab; for the prevention of angioedema attacks) (Fig. 4).

Plecanatide (Trulance®) is a 16-amino acid peptide with an amino acid sequence similar to uroguanylin. It

[96] Drugs.com. Eucrisa. Available from: https://www.drugs.com/eucrisa.html
[97] Drugs.com. Kerydin. Available from: https://www.drugs.com/kerydin.html
[98] Drugs.com. Kovanaze. Available from: https://www.drugs.com/pro/kovanaze.html
[99] Drugs.com. Adlyxin Available from: https://www.drugs.com/adlyxin.html
[100] Drugs.com. Soliqua. Available from: https://www.drugs.com/soliqua.html
[101] Drugs.com. Xultophy. Available from: https://www.drugs.com/xultophy.html
[102] Drugs.com. Zepatier. Available from: https://www.drugs.com/zepatier.html
[103] Drugs.com. Epclusa. Available from: https://www.drugs.com/epclusa.html
[104] Drugs.com. Viekira. Available from: https://www.drugs.com/viekira.html
[105] Drugs.com. Vemlidy. Available from: https://www.drugs.com/vemlidy.html
[106] Drugs.com. Syndros Available from: https://www.drugs.com/mtm/syndros.html
[107] Drugs.com. Ephedrine (Monograph). Available from: https://www.drugs.com/monograph/ephedrine.html
[108] Drugs.com. Byvalson. Available from: https://www.drugs.com/byvalson.html
[109] Drugs.com. Nitroglycerin (oral/sublingual). Available from: https://www.drugs.com/mtm/ nitroglycerin-oral-sublingual.html
[110] Drugs.com. Qbrelis. Available from: https://www.drugs.com/mtm/qbrelis.html
[111] Drugs.com. Yosprala. Available from: https://www.drugs.com/yosprala.html

activates guanylate cyclase-C on endothelial cells of the gastrointestinal tract, which leads to phosphorylation mediated by protein kinase A and protein kinase G II of the cystic fibrosis transmembrane conductance regulator protein, upon activation of which negatively charged ions (Cl^- and HCO_3^-) are released into the lumen of the gastrointestinal tract. This ensures the entry of Na^+ and water ions, providing a laxative effect. It is indicated for the treatment of chronic idiopathic constipation and irritable bowel syndrome with constipation[112].

Etelcalcetide (Parsabiv®) is a new drug for the treatment of secondary hyperparathyroidism in people undergoing hemodialysis, acts through activation of the calcium-sensing receptor in the parathyroid gland, which leads to a decrease and suppression of parathyroid hormone secretion. Interestingly, by nature it is a peptide consisting mainly of D-amino acids instead of the usual L-amino acids[113].

Abaloparatide (Tymlos®) is a synthetic analogue of parathyroid hormone, consisting of 34 amino acids, acts as an anabolic agent on bone tissue through selective activation of parathyroid hormone receptor 1, expressed in osteoblasts and osteocytes. Approved for the treatment of postmenopausal osteoporosis[114].

The first tryptophan hydroxylase inhibitor (involved in serotonin biosynthesis) is a telotristat (Xermelo®) approved for the treatment of adults with diarrhea associated with carcinoid syndrome[115].

Safinamide (Xadago®) (synthesized in 1993) is approved for the treatment of Parkinson's disease[116]. Like selegiline and rasagiline, it is a selective inhibitor of monoamine oxidase B, but unlike them, it is reversible. Safinamide also affects the metabolism of glutamate, dopamine and serotonin, interacts with sigma receptors, blocks Ca^{2+}- and Na^+-channels.

Valbenazine (Ingrezza®) is a prodrug, an ester of [+]-α-dihydrotetrabenazine with the amino acid L-valine, the first drug approved for the treatment of drug-induced dyskinesia. It acts as an inhibitor of the presynaptic vesicular monoamine transporter type 2 in humans, reducing dopamine secretion[117].

Cerliponase α (Brineura®) is the first drug for the treatment of Batten disease (juvenile form of a group of diseases called neuronal ceroid lipofuscinoses), which occurs as a result of a genetic mutation in battenin — a protein encoded by the *CLN3* gene and causing a deficiency of tripeptidylpeptidase-1. The drug is an enzyme replacement agent (functions as a serine protease, a recombinant form of TPP1)[118].

Another anticoagulant drug has been approved — betrixaban (Bevyxxa®) — a direct inhibitor of activated coagulation factor X, for the prevention of venous thrombosis, is practically not metabolized by cytochrome CYP3A4 and does not have significant renal excretion, which distinguishes it from drugs with a similar mechanism of action[119].

For the treatment of precocious puberty, triptorelin (Triptodur®) has been approved (patented in 1975 and approved for medical use in 1986) — a decapeptide and agonist of gonadotropin-releasing hormone, suppresses the expression of luteinizing hormone (LH) and follicle-stimulating hormone, reduces the secretion of androgens and estrogens[120].

Secnidazole (Solosec®) (a 5-nitroimidazole derivative, structurally similar to metronidazole) is approved as an antimicrobial and antiprotozoal agent. It has a bactericidal effect against most anaerobic bacteria and many protozoa, including trichomonads. The mechanism of action is based on the ability to disrupt the coiling of DNA of microbial cells, cause a break in its strands; suppress the synthesis of nucleic acids; inhibit reduction processes characteristic of anaerobes[121].

Exenatide (Bydureon BCise) is approved as a new antidiabetic drug (GLP-1 receptor agonist), which, unlike its predecessor, is administered once a week instead of 2 injections per day[122]. A drug containing another synthetic GLP-1 analogue, semaglutide

[112] Drugs.com. Trulance. Available from: https://www.drugs.com/trulance.html
[113] Drugs.com. Parsabiv. Available from: https://www.drugs.com/mtm/parsabiv.html
[114] Drugs.com. Tymlos. Available from: https://www.drugs.com/tymlos.html
[115] Drugs.com. Xermelo. Available from: https://www.drugs.com/xermelo.html
[116] Drugs.com. Xadago. Available from: https://www.drugs.com/xadago.html
[117] Drugs.com. Ingrezza. Available from: https://www.drugs.com/ingrezza.html
[118] Drugs.com. Brineura. Available from: https://www.drugs.com/brineura.html
[119] Drugs.com. Bevyxxa. Available from: https://www.drugs.com/bevyxxa.html
[120] Drugs.com. Triptodur. Available from: https://www.drugs.com/mtm/triptodur.html
[121] Drugs.com. Solosec. Available from: https://www.drugs.com/solosec.html
[122] Drugs.com. Bydureon. Available from: https://www.drugs.com/bydureon.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

(Ozempic®), has also been approved for the treatment of T2DM and to reduce the risk of its cardiovascular complications[123]. Ertugliflozin (Steglatro®), a sodium / glucose cotransporter 2 inhibitor, and its combinations with metformin (biguanide) (Segluromet®)[124] or sitagliptin (DPP-4i; Steglujan®)[125] have also been approved as antihyperglycemic agents.

Voretigene neparvovec (Luxturna®) — AAV2 vector containing human cDNA RPE65 with a modified Kozak sequence, is indicated for the treatment of people with vision loss due to inherited retinal dystrophy with confirmed biallelic RPE65 mutations, and who have a sufficient number of viable retinal cells (the first gene therapy drug for the treatment of congenital Leber's amaurosis, the first approved gene therapy)[126].

For the diagnosis of growth hormone deficiency, macimorelin (Macrilen®) (D-tryptophanamide, 2-methylalanyl-N-[(1R)-1-(formylamino)-2-(1H-indol-3-yl) ethyl] acetate; ghrelin receptor agonist, causing the release of growth hormone from the pituitary gland) has been approved. Traditionally, growth hormone deficiency was diagnosed using an insulin tolerance test or a glucagon stimulation test [31]. These two agents are administered parenterally, whereas the approved macimorelin is administered orally[127].

Glycopyrrolate (Lonhala Magnair®) was first used in 1961 to treat peptic ulcer disease. Since 1975, intravenous glycopyrronium has been used before surgery to reduce salivary, tracheobronchial, and pharyngeal secretions — a muscarinic receptor antagonist, inhibits cholinergic transmission and is approved for the treatment of COPD [32]. In 2021, it was approved for therapy in peptic ulcer due to its ability to reduce hydrochloric acid secretion[128].

The first-in-class drug letermovir (Prevymis®) is approved for the prevention of cytomegalovirus (CMV) infection and other diseases in allogeneic stem cell transplant recipients. It acts as a specific inhibitor of the CMV-terminase complex, which is encoded by the CMV genes *UL56*, *UL51*, and *UL89*. This inhibition prevents the cleavage of CMV DNA concatamers, resulting in long, unprocessed DNA and non-infectious viral particles. Letermovir is active only against CMV and does not affect other herpes viruses[129].

Vestronidase α (Mepsevii®) deserves attention as the only drug for the treatment of Sly syndrome (mucopolysaccharidosis type VII) and is a recombinant form of the human enzyme β-glucuronidase[130]. Macimorelin (Macrilen®) is an agonist of receptors that enhance the secretion of growth hormone (ghrelin receptors) from the pituitary gland and is used for diagnostic purposes in adults[131].

2018

In 2018, the FDA approved 110 drugs, 57 of which were new molecular entities (including 37 biologicals), 13 were new drug combinations, 2 were reproduced drugs; 28 drugs had a new dosage form or a new indication for use. It should also be noted that 19 drugs were first-in-class, 34 drugs were intended for the treatment of rare diseases, and seven biosimilars were approved. Examples of registered drugs were cannabidiol[132] (Epidiolex®; the first drug derived from marijuana approved for the treatment of epilepsy associated with Lennox-Gastaut and Dravet syndromes)[133], stiripentol (Diacomit®; the second drug approved for the treatment of Dravet syndrome [severe myoclonic epilepsy of infancy])[134], migalastat (Galafold®; the first oral drug for the treatment of Fabry disease [an extremely rare lysosomal storage disease])[135], burosumab (Crysvita®; the first drug for the treatment of X-linked hypophosphatemic rickets)[136], pegvaliaza (Palynziq®; the first approved drug for the treatment of phenylketonuria)[137], as well as three new drugs for the prevention of migraine —

[123] Drugs.com. Ozempic. Available from: https://www.drugs.com/ozempic.html
[124] Drugs.com. Segluromet. Available from: https://www.drugs.com/segluromet.html
[125] Drugs.com. Steglujan. Available from: https://www.drugs.com/steglujan.html
[126] Drugs.com. FDA Approves Luxturna. Available from: https://www.drugs.com/newdrugs/fda-approves-luxturna-voretigene-neparvovec-rzyl-gene-therapy-patients-rare-inherited-vision-loss-4662.html
[127] Drugs.com. Macrilen. Available from: https://www.drugs.com/mtm/macrilen.html
[128] Drugs.com. Lonhala Magnair Starter Kit (inhalation). Available from: https://www.drugs.com/ mtm/lonhala-magnair-starter-kit-inhalation.html
[129] Drugs.com. Prevymis. Available from: https://www.drugs.com/prevymis.html
[130] Drugs.com. Mepsevii. Available from: https://www.drugs.com/mtm/mepsevii.html
[131] Drugs.com. Macrilen. Available from: https://www.drugs.com/mtm/macrilen.html
[132] Starting in 2018, cannabidiol (i.e. CBD oil) is no longer prohibited under the S8 Cannabinoids category.
[133] Drugs.com. Epidiolex Available from: https://www.drugs.com/epidiolex.html
[134] Drugs.com. Diacomit. Available from: https://www.drugs.com/diacomit.html
[135] Drugs.com. Galafold. Available from: https://www.drugs.com/galafold.html
[136] Drugs.com. Crysvita. Available from: https://www.drugs.com/mtm/crysvita.html
[137] Drugs.com. Palynziq. Available from: https://www.drugs.com/palynziq.html

erenumab (Aimovig®)[138], fremanezumab (Ajovy®)[139] and galcanezumab (Emgality®)[140] (Fig. 7).

In 2018, tolvaptan (Jynarque®) was approved for the treatment of adults at risk of rapidly progressing autosomal dominant polycystic kidney disease, which was previously used to treat hypervolemic and euvolemic hyponatremia, and which acts as a selective competitive vasopressin receptor 2 antagonists[141]. Lofexidine hydrochloride (Lucemyra®) is the first non-opioid drug for the treatment of opioid withdrawal syndrome, acting as an α2-adrenergic receptor agonist and is structurally similar to clonidine, but unlike the latter, it reduces blood pressure to a lesser extent[142]. Widely known in veterinary practice moxidectin, a macrocyclic lactone of the milbemycin class, widely known in veterinary practice (macrolides, first isolated in 1972 from *Streptomyces hygroscopicus*), the mechanism of action associated with the opening of glutamate-sensitive chlorine channels in neurons and myocytes of invertebrates, which leads to hyperpolarization and blocking of signal transmission [33], is approved for use in onchocerciasis[143].

The antibiotic plazomicin (Zemdri®) (first submitted for review in 2012, derived from sisomicin, which is structurally closest to gentamicin) acts as an aminoglycoside antibiotic and is approved for the treatment of complicated urinary tract infections[144].

Glycopyrronium (Qbrexza®) (blocks muscarinic receptors and suppresses cholinergic transmission; does not penetrate the blood-brain barrier) was first used in 1961 to treat peptic ulcer disease, and since 1975 its intravenous administration has been used before surgery to reduce salivary, tracheobronchial, and pharyngeal secretions [32], and in 2018 it was approved for the treatment of hyperhidrosis[145].

Tecovirimat (TPOXX®) is an antiviral drug active against orthopoxviruses, such as smallpox and monkeypox (mpox), the first in its class (synthesis published in 2004), suppresses the function of the orthopoxvirus envelope protein VP37, the main envelope protein required for the production of extracellular virus, prevents the virus from leaving the infected cell, preventing the spread of the virus in the body[146].

For the prevention and treatment of malaria, tafenoquine (Krintafel® and Arakoda®)[147,148] (structurally similar to primaquine [first produced in 1946], chloroquine [was discovered in 1934] and mefloquine [developed in the 1970s]) has been approved, which belongs to the family of 8-aminoquinoline drugs, the mechanism of antimalarial action is poorly understood.

Elagolix (Orilissa®) was first described in 2008 [34], but was approved for medical use only in July 2018, as a potent and selective competitive antagonist of the gonadotropin-releasing hormone (GnRH) receptor of the "second generation" due to its non-peptide, low molecular weight nature, which allows it to be used orally. The drug is used to treat moderate to severe pain caused by endometriosis[149]. The drug is the first in its class, after it relugolix was created (approved in 2022 for the treatment of prostate cancer).

Eravacycline (Xerava®) is a new synthetic halogenated antibiotic of the tetracycline class[150], also from this group (tetracyclines) sarecycline (Seysara®) (a narrow-spectrum antibiotic) was approved for the treatment of acne[151]. Unlike other antibiotics in this group, the drug has a long C7 fragment, thanks to which it directly interacts with bacterial mRNA. This compound was obtained during chemical experiments with tetracycline cascades, which also resulted in the development of another third-generation tetracycline antibiotic — omadacycline (Nuzyra®) for the treatment of community-acquired bacterial pneumonia and acute skin infections[152].

[138] Drugs.com. Aimovig. Available from: https://www.drugs.com/aimovig.html
[139] Drugs.com. Ajovy. Available from: https://www.drugs.com/ajovy.html
[140] Drugs.com. Emgality. Available from: https://www.drugs.com/emgality.html
[141] Drugs.com. Jynarque. Available from: https://www.drugs.com/mtm/jynarque.html
[142] Drugs.com. Lucemyra. Available from: https://www.drugs.com/lucemyra.html
[143] Drugs.com. FDA Approves Moxidectin. Available from: https://www.drugs.com/newdrugs/fda-approves-moxidectin-river-blindness-4766.html
[144] Drugs.com. FDA Approves Zemdri. Available from: https://www.drugs.com/newdrugs/zemdri-plazomicin-approved-fda-adults-complicated-urinary-tract-infections-cuti-4770.html
[145] Drugs.com. Qbrexza (glycopyrronium cloth). Available from: https://www.drugs.com/mtm/qbrexza-glycopyrronium-cloth.html
[146] Drugs.com. TPOXX. Available from: https://www.drugs.com/tpoxx.html
[147] Drugs.com. Krintafel. Available from: https://www.drugs.com/mtm/krintafel.html
[148] Drugs.com. Arakoda. Available from: https://www.drugs.com/arakoda.html
[149] Drugs.com. Orilissa Play pronunciation. Available from: https://www.drugs.com/orilissa.html
[150] Drugs.com. Xerava. Available from: https://www.drugs.com/mtm/xerava.html
[151] Drugs.com. Seysara. Available from: https://www.drugs.com/seysara.html
[152] Drugs.com. Nuzyra (oral/injection). Available from: https://www.drugs.com/mtm/nuzyra-oral-injection.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

Baloxavir marboxil (Xofluza®) is a prodrug, an inhibitor of the enzyme that synthesizes viral mRNA. It is used as an antiviral agent, including for the treatment of acute uncomplicated influenza in people aged twelve years and older who are at risk of influenza complications (since 2019)[153].

Latanoprost (Xelpros®) is a prostaglandin analogue (prostaglandin F2α) in the form of eye drops for the treatment of glaucoma and high intraocular pressure, by stimulating the outflow of aqueous humor through the uveoscleral pathway; prodrug — inactive until hydrolyzed in the cornea from ether to biologically active acids[154].

For the treatment of COPD, an inhalation solution containing revefenacin (Yupelri®) has been approved — a bronchodilator, a long-acting muscarinic receptor antagonist[155].

Prucalopride (Motegrity®) acts as a selective, high-affinity 5-HT4 receptor agonist for the treatment of chronic intestinal pseudo-obstruction[156].

2019

In 2019, the FDA approved 100 drugs, and 57 drugs registration was made for original molecules (including 31 of biologicals), in 14 — for new combinations, in 2 — for reproduced drugs; 16 drugs had a new dosage form or a new indication for use. Notable examples of approved drugs are tafamidis (Vyndaqel®; for the treatment of transthyretin familial amyloid polyneuropathy)[157], fedratinib (Inrebic®; for the treatment of myelofibrosis)[158], luspatercept (Reblozyl®; for the treatment of anemia associated with β-thalassemia)[159], romosozumab (Evenity®; for the treatment of osteoporosis in postmenopausal women)[160], upadacitinib (Rinvoq®; for the treatment of rheumatoid arthritis)[161] (Fig. 8).

Triclabendazole (Egaten®) is approved for the treatment of fascioliasis[162] (previously used to combat paragonimiasis), unlike classic benzimidazoles, does not have a carbamate group, but the structure contains a chlorinated benzene ring; all drugs in this class bind to β-tubulin, thereby preventing microtubule polymerization [35]. It has had non-proprietary drug status since 1990.

Allopregnanolone (3-α,5-α-tetrahydroprogesterone, 3α,5α-THP; Zulresso®) is a metabolite of allopregnanedione (synthesized from progesterone; a progesterone receptor agonist, a positive allosteric modulator of the GABAA receptor, and a negative allosteric modulator of the GABAA-rho receptor), synthesized both by the adrenal cortex and directly in the brain with the participation of 5-α-reductase and 3-α-hydroxysteroid oxidoreductase. It plays a multifaceted role in the development of the central nervous system, binding to a special structural site on its surface and modulating the activity of the GABA-A receptor [36]. Zulresso® is approved for the treatment of postpartum depression[163].

Esketamine (Spravato®), which has a high antagonism to NMDA receptors, deserves attention. Approved as a nasal spray for the treatment of resistant depression and major depressive disorder with concomitant suicidal thoughts or behavior[164].

Duobrii® is approved for the treatment of psoriasis — the first combination of halobetasol (topical corticosteroid; has immunosuppressive, anti-inflammatory, and antiproliferative effects) and tazarotene (third-generation retinoid, agonist of retinoic acid receptors (RAP-α, RAP-β, RAP-γ; normalizes the differentiation of keranocytes, inhibits their proliferation, and reduces the expression of inflammatory markers; approved in the same year as a single drug for the treatment of acne). The effects of these substances organically complement each other, reducing the irritating effect (of tazarotene) or prolonging the action (of halobetasol)[165].

Qternmet XR® is approved for the treatment

[153] Drugs.com. Xofluza. Available from: https://www.drugs.com/xofluza.html
[154] Drugs.com. Xelpros. Available from: https://www.drugs.com/mtm/xelpros.html
[155] Drugs.com. Yupelri Inhalation. Available from: https://www.drugs.com/yupelri.html
[156] Drugs.com. Motegrity. Available from: https://www.drugs.com/motegrity.html
[157] Drugs.com. Vyndaqel. Available from: https://www.drugs.com/vyndaqel.html
[158] Drugs.com. Inrebic. Available from: https://www.drugs.com/inrebic.html
[159] Drugs.com. Reblozyl. Available from: https://www.drugs.com/reblozyl.html
[160] Drugs.com. Evenity. Available from: https://www.drugs.com/evenity.html
[161] Drugs.com. Rinvoq. Available from: https://www.drugs.com/rinvoq.html
[162] Drugs.com. Triclabendazole (Monograph). Available from: https://www.drugs.com/monograph/ triclabendazole.html
[163] Drugs.com. Zulresso. Available from: https://www.drugs.com/zulresso.html
[164] Drugs.com. Spravato. Available from: https://www.drugs.com/spravato.html
[165] Drugs.com. Duobrii. Available from: https://www.drugs.com/duobrii.html

of T2DM — the first combination of dapagliflozin, metformin hydrochloride, and saxagliptin[166].

Tafamidis meglumine (Vyndaqel®; selective transthyretin stabilizer; binds to two thyroxine-binding sites of transthyretin in its native [tetrameric] form, which prevents dissociation of the complex into monomers and slows amyloidogenesis) is approved for the treatment of cardiomyopathy and amyloidosis[167].

Onasemnogene abeparvovec (Zolgensma®) is approved — the first drug for gene therapy for spinal muscular atrophy, for use in children under 2 years old[168].

Budesonide (Ortikos®) is approved for the treatment of Crohn's disease[169].

Bremelanotide (Vyleesi®)[170] is used for low sexual desire that occurs before menopause. Bremelanotide is a non-selective agonist of melanocortin receptors MC1–MC5 (except MC2 — the ACTH receptor), but acts primarily as an agonist of MC3 and MC4 receptors. It is a cyclic heptapeptide lactam analog of αmelanocyte-stimulating hormone (α-MSH), an active metabolite of melanotan II, which lacks the Cterminal amide group [37]. In addition to melanotan II and endogenous melanocyte-stimulating hormones, such as α-MSH, other peptide analogs of the same family as bremelanotide include afamelanotide (NDP-α-MSH), modimelanotide, and setmelanotide [38].

Amlodipine besylate (Katerzia™) in a new dosage form is approved for the treatment of hypertension and coronary artery disease[171].

Recarbrio™ is approved for the treatment of genitourinary infections — a combination of imipenem (synthetic β-lactam antibiotic), cilastatin (human dehydropeptidase inhibitor that prevents the degradation of imipenem), and relabactam (β-lactamase inhibitor).

A new anti-tuberculosis drug has been approved. Pretomanid (Dovprela®)[172] is activated in mycobacteria by deazaflavin-dependent nitroreductase (Ddn) and converted into a highly active metabolite. This metabolite attacks the DprE2 synthesis enzyme, which is necessary for the synthesis of the cell wall arabinogalactan, to which mycolic acid will be attached; this mechanism is common with delamanid [39].

Tenapanor (Ibsrela®) is an inhibitor of the Na^+/H^+ exchanger (NHE3), the antiport protein is located in the kidneys and intestines, regulating the levels of sodium absorbed and excreted by the body), selectively inhibits sodium absorption in the intestine, limiting the amount absorbed from food, and thereby reduces the level of sodium in the body, which may be potentially useful in kidney disease and/or hypertension [40]. In October 2023, tenapanor was approved by the FDA for the treatment of hyperphosphatemia[173].

Semaglutide (Rybelsus®) (aGLP-1) is approved in tablet form for oral administration[174].

Trifarotene (Aklief®) is approved as a drug for the topical treatment of acne. It is a retinoid — a selective agonist of the fourth-generation retinoic acid receptor RAR-γ[175].

Lasmiditan (Reyvow®) — a selective agonist of 5-HT1F serotonin receptors selectively binds to this subtype of receptors, and the lack of affinity for 5-HT1B and 5-HT1D increases its safety[176].

Minocycline (Amzeeq®) (binds to the 30S ribosomal subunit of bacteria and thereby inhibits protein synthesis), which was patented in 1961, has been approved as a drug for the topical treatment of acne (foam)[177].

For the first time, a triple combination for the treatment of cystic fibrosis has been approved — elexacaftor, tezacaftor, and ivacaftor (Trikafta®). All substances are classified as cystic fibrosis transmembrane regulators (CFTR) in cystic fibrosis[178].

A new combination of amoxicillin (antibiotic, aminopenicillins of the penicillin family; inhibits cross-links between linear polymer chains of peptidoglycan, which is the main component of the bacterial cell

[166] Drugs.com. Qternmet XR. Available from: https://www.drugs.com/qternmet-xr.html
[167] Drugs.com. Vyndaqel Play pronunciation. Available from: https://www.drugs.com/vyndaqel.html
[168] Drugs.com. Zolgensma. Available from: https://www.drugs.com/zolgensma.html
[169] Drugs.com. Ortikos. Available from: https://www.drugs.com/mtm/ortikos.html
[170] Drugs.com. Vyleesi. Available from: https://www.drugs.com/vyleesi.html
[171] Drugs.com. Katerzia. Available from: https://www.drugs.com/mtm/katerzia.html
[172] Drugs.com. FDA Approves Pretomanid. Available from: https://www.drugs.com/newdrugs/fda-approves-pretomanid-highly-resistant-forms-tuberculosis-5029.html
[173] Drugs.com. Ibsrela. Available from: https://www.drugs.com/ibsrela.html
[174] Drugs.com. Rybelsus. Available from: https://www.drugs.com/rybelsus.html
[175] Drugs.com. Aklief. Available from: https://www.drugs.com/aklief.html
[176] Drugs.com. Reyvow. Available from: https://www.drugs.com/reyvow.html
[177] Drugs.com. Amzeeq. Available from: https://www.drugs.com/mtm/amzeeq.html
[178] Drugs.com. Trikafta. Available from: https://www.drugs.com/trikafta.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

wall; developed in the 1960s), omeprazole (proton pump inhibitor, patented in 1978), and rifabutin (antibiotic, blocks DNA-dependent RNA polymerase, discovered in 1975) — the drug Talicia® has been approved for the treatment of Helicobacter pylori infection[179].

A new antibiotic, cefiderocol (Fetroja®), has been approved, which is structurally similar to cefepime and ceftazidime, but the chlorocatechol group at the end of the C-3 side chain further increases its stability to β-lactamase and makes it a siderophore (small, high-affinity iron-chelating compounds, one of the strongest known Fe^{3+} chelators)[180].

Cenobamate (Xcopri®) is a blocker of potential-dependent Na^+ channels, predominantly inhibiting the constant sodium current, additionally enhances the presynaptic release of γ-aminobutyric acid, increasing inhibitory GABAergic neurotransmission, and is approved for use in epilepsy[181].

Golodirsen (Vyondys 53®) is approved for the treatment of Duchenne muscular dystrophy, causing exon skipping in the dystrophin gene and thereby increasing the amount of dystrophin protein available to muscle fibers[182].

Levamlodipine (Conjupri®) — the pharmacologically active enantiomer of amlodipine — a dihydropyridine calcium channel blocker used as an antihypertensive and antianginal agent, the key advantage of which (like all enantiomers) is a 2-fold reduction in the effective dose compared to traditional amlodipine drugs (patented in 1982)[183].

Lumateperone (Caplyta®) is approved for the treatment of Schizophrenia and the depressive phase of bipolar disorder, both as monotherapy and as adjunctive therapy (with lithium or valproate), acts as a 5-HT2A receptor antagonist and an antagonist of several dopamine receptor subtypes (D1R, D2R, and D4R), but with lower affinity. It moderately inhibits serotonin transporter reuptake and has additional off-target antagonism against α-1 receptors, without noticeable antimuscarinic or antihistaminergic properties, limiting the side effects associated with other atypical antipsychotics[184].

Lemborexant (Dayvigo®) is a dual orexin antagonist (orexin receptor antagonist OX1 and OX2) that is used to treat insomnia and, unlike suvorexant, has a short duration of action[185]. Ubrogepant (Ubrelvy®) is approved for the treatment of migraine and acts as an antagonist of the calcitonin gene-related peptide receptor[186].

2020

In 2020, against the backdrop of the COVID-19 pandemic, 104 drugs were registered, including 50 original ones (including 30 biologicals), 14 new combinations, 3 reproduced drugs, and 21 drugs in a new dosage form or with a new indication for use. A high proportion of biologicals, including antibodies and therapeutic vaccines, as well as drugs intended for the treatment of orphan diseases, also persisted, which underscores the importance of developing therapies for small groups of patients. Among the approved drugs, remdesivir (Veklury®; antiviral agent for the treatment of COVID-19)[187], formoterol bromide and glycopyrronium bromide (Breztri Aerosphere®; for the treatment of chronic obstructive pulmonary disease [COPD])[188], carfilzomib (Kyprolis®; for the treatment of relapsed or refractory multiple myeloma)[189], loncastuzumab (Zynlonta®; for the treatment of relapsed or refractory non-Hodgkin's lymphoma)[190], and teplizumab (Tzield®; to slow the progression of type 1 diabetes)[191] can be distinguished (Fig. 9).

A new dosage form (nasal spray) for diazepam[192] (Valtoco®) (a benzodiazepine, a positive allosteric modulator of GABA type A receptors, a derivative of

[179] Drugs.com. Talicia. Available from: https://www.drugs.com/mtm/talicia.html
[180] Drugs.com. Fetroja. Available from: https://www.drugs.com/mtm/fetroja.html
[181] Drugs.com. Xcopri. Available from: https://www.drugs.com/xcopri.html
[182] Drugs.com. Vyondys 53. Available from: https://www.drugs.com/vyondys-53.html
[183] Drugs.com. Conjupri. Available from: https://www.drugs.com/mtm/conjupri.html
[184] Drugs.com. Caplyta. Available from: https://www.drugs.com/caplyta.html
[185] Drugs.com. Dayvigo. Available from: https://www.drugs.com/dayvigo.html
[186] Drugs.com. Ubrelvy. Available from: https://www.drugs.com/ubrelvy.html
[187] Drugs.com. Veklury. Available from: https://www.drugs.com/veklury.html
[188] Drugs.com. Breztri. Available from: https://www.drugs.com/breztri-aerosphere.html
[189] Drugs.com. Kyprolis. Available from: https://www.drugs.com/kyprolis.html
[190] Drugs.com. Zynlonta. Available from: https://www.drugs.com/zynlonta.html
[191] Drugs.com. Tzield. Available from: https://www.drugs.com/tzield.html
[192] Decree of the Government of the Russian Federation of June 30, 1998 No. 681 "On Approval of the List of Narcotic Drugs, Psychotropic Substances and their Precursors Subject to Control in the Russian Federation" (with Amendments and additions). Available from: https://base.garant.ru/12112176/. Russian

chlordiazepoxide [approved in 1960] has been available for clinical use since 1963) [41] has been approved for the relief of epileptic seizures, including in children[193].

A triple combination of hypoglycemic drugs — Trijardy XR® (empagliflozin [SGLT2i], linagliptin [DPP-4i], and metformin hydrochloride [biguanide]) has been approved for the treatment of T2DM[194].

Pizensy®, a drug containing lactitol (a disaccharide sugar alcohol, a derivative of lactose), which was previously widely used as an excipient, has been approved for the treatment of chronic idiopathic constipation[195].

Bempedoic acid (Nexletol®) has been app roved as the first in-class drug for the treatment of hypercholesterolemia[196]. It is a prodrug that is transformed into a thioether with the participation of coenzyme A and the enzyme acyl-CoA synthetase with a very long chain SLC27A2 in the liver, after which it inhibits ATP-citrate lyase, which is involved in cholesterol biosynthesis in the liver above HMG-CoA reductase, an enzyme that is blocked by statins. Almost immediately after this registration, a drug containing bempedoic acid and ezetimibe (Nexlizet®), which inhibits the absorption of cholesterol from the small intestine and reduces the bioavailability of cholesterol, was approved. Ezetimibe blocks a critical mediator of cholesterol absorption, Niemann-Pick C1-Like 1 protein (NPC1L1) on gastrointestinal epithelial cells, and in hepatocytes it blocks aminopeptidase N and disrupts the caveolin 1 — annexin A2 complex involved in cholesterol transport [42] The drug is also approved for the treatment of heterozygous familial hypercholesterolemia[197].

Rimegepant (Nurtec® ODT) is a small molecule antagonist of the calcitonin gene-related peptide receptor (for oral administration) approved for the treatment and prevention (in 2021) of migraine[198]. Eptinezumab (Vyepti®; intravenous injections), a fully human monoclonal antibody that blocks the binding of calcitonin gene-related peptide to its receptor, has been approved for the same indication[199].

Osilodrostat (Isturisa®) (an inhibitor of steroidogenesis enzymes) — steroid 11β-hydroxylase and aldosterone synthase for the treatment of adults with Cushing's disease[200].

Ozanimod (Zeposia®) is approved for the treatment of relapsing multiple sclerosis and ulcerative colitis, acting as an agonist of the sphingosine-1-phosphate receptor (S1PR), which causes its internalization and degradation via the ubiquitin-proteasome pathway, leading to the isolation of lymphocytes in peripheral lymphoid organs and away from sites of chronic inflammation[201]. This compound is more selective than siponimod, fingolimod, and mocravimod.

Selumetinib (Koselugo®) is approved as a drug for the treatment of children aged two years and older with neurofibromatosis type I (NF-1), a genetic disorder of the nervous system that causes tumors to grow on nerve tissue; it is a kinase inhibitor (selective inhibitor of the enzyme mitogen-activated protein kinase kinase [MAPK kinase] subtypes 1 and 2), which is part of the MAPK/ERK pathway that regulates cell proliferation and is overactive in many types of cancer[202].

Mitomycin (Jelmyto®) (discovered in 1955 by Japanese scientists in cultures of the microorganism *Streptomyces caespitosus*; structurally similar to rifamycin and ansamycin), is a potent DNA crosslinker, which is effective for killing bacteria. As an alkylating agent, it inhibits the transcription of DNA into RNA, stopping protein synthesis and depriving cancer cells of the ability to multiply[203].

Opicapone (Ongentys®) is approved for the treatment of Parkinson's disease, effectively blocking the enzyme catechol-O-methyltransferase (>90% at therapeutic doses), which breaks down levodopa, sele ctively and reversibly, and only outside the central nervous system, which ensures greater penetration into the CNS and increased efficacy[204].

Monomethyl fumarate (Bafiertam®) is approved

[193] Drugs.com. Valtoco. Available from: https://www.drugs.com/valtoco.html
[194] Drugs.com. Trijardy XR. Available from: https://www.drugs.com/trijardy-xr.html
[195] Drugs.com. Pizensy. Available from: https://www.drugs.com/pro/pizensy.html
[196] Drugs.com. Nexletol. Available from: https://www.drugs.com/nexletol.html
[197] Drugs.com. Nexlizet. Available from: https://www.drugs.com/nexlizet.html
[198] Drugs.com. Nurtec ODT. Available from: https://www.drugs.com/nurtec-odt.html
[199] Drugs.com. Vyepti. Available from: https://www.drugs.com/vyepti.html
[200] Drugs.com. Isturisa. Available from: https://www.drugs.com/isturisa.html
[201] Drugs.com. Zeposia. Available from: https://www.drugs.com/zeposia.html
[202] Drugs.com. Koselugo. Available from: https://www.drugs.com/koselugo.html
[203] Drugs.com. Jelmyto (gel). Available from: https://www.drugs.com/mtm/jelmyto-gel.html
[204] Drugs.com. Ongentys. Available from: https://www.drugs.com/ongentys.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

for the treatment of multiple sclerosis[205], acting by altering the nuclear transcription factor associated with erythroid factor 2 (nuclear factor erythroid 2-related factor 2, NFE2L2) — a basic leucine zipper protein — which regulates the expression of antioxidant proteins that protect against oxidative damage caused by trauma and inflammation [43]. Several drugs that stimulate the NFE2L2 pathway are being studied for the treatment of diseases caused by oxidative stress.

Two precursors, dimethyl fumarate (in 2013) and diroximel fumarate (in 2019), were previously approved. The first medical use of fumaric acid for the treatment of psoriasis was described in 1959 (local form), and the oral form appeared in 1994 [44].

Leuprorelin (Camcevi®) (was patented in 1973 and approved for medical use in 1985) is an analogue of GnRH, acting as an agonist of pituitary GnRH receptors, increases the secretion of LH and FSH by the anterior pituitary gland, increases serum estradiol and testosterone levels via the hypothalamic-pituitary-gonadal axis (HPG axis) [45]. Approved for the treatment of precocious puberty[206]. A combination containing leuprorelin / norethisterone acetate was previously approved (2012) for the treatment of endometriosis.

Artesunate (water-soluble hemisuccinate of dihydroartemisinin, a derivative of artemisinin; developed, like lumefantrine, piperaquine, and pyronaridine) is approved for the treatment of malaria. The first publications appeared in 1979. It is used both in monotherapy and in combinations (artesunate / pyronaridine, arterolan/ piperaquine, artemisinin base / piperaquine, and artemisinin / naphthoquine)[207].

Trigheptanoin (Dojolvi®) is approved as a drug for the treatment of children and adults with molecularly confirmed long-chain fatty acid oxidation disorders[208].

Remimazolam (Byfavo®)[209] — a benzodiazepine, enhances the action of the endogenous neurotransmitter GABA on GABAA receptors (increasing the frequency of Cl^- channel opening) — a drug that was synthesized in the late 1990s [46], approved as an alternative to midazolam (patented in 1974) for the induction and maintenance of procedural sedation in adults during invasive diagnostic or surgical procedures lasting 30 minutes or less[210].

Nifurtimox (Lampit®) began to be used in medicine in 1965, and received FDA approval for the treatment of Chagas disease only in 2020. Its mechanism of action is similar to metronidazole (1950s, nitroimidazole) (forms a nitro-anion-radical metabolite that reacts with the nucleic acids of the parasite, causing significant DNA breakage)[211].

The first oral drug for the treatment of spinal muscular atrophy, risdiplam (Evrysdi®)[212] (a pyridazine derivative), has been approved — an RNA splicing modifier aimed at the survival of motor neuron 2 (reduces the decrease in survival motor neuron protein; the first drug with a similar mechanism of action was nusinersen [approved in 2016; see above]). Viltolarsen (Viltepso®)[213] has been approved for the treatment of Duchenne muscular dystrophy, which, like eteplirsen (approved in 2016) and golodirsen (approved in 2019), is a phosphorodiamidate antisense morpholino oligonucleotide, a structural analogue of DNA that binds to exon 53 of dystrophin pre-mRNA, implementing its alternative splicing by skipping during mRNA processing and thereby (by restoring the reading frame) ensuring the synthesis of an internally truncated but functional dystrophin. The production of the latter compensates for the critical deficiency of this protein in Duchenne muscular dystrophy [47].

Clascoterone (Winlevi®) (cortexolone 17α-propionate) is approved as the first in-class drug for the treatment of hidradenitis suppurativa (inverse acne — an androgen-dependent skin disease), which acts as an antiandrogen or androgen receptor antagonist, the biological target of androgens such as testosterone and dihydrotestosterone[214].

[205] Drugs.com. Bafiertam. Available from: https://www.drugs.com/mtm/bafiertam.html
[206] Drugs.com. Camcevi. Available from: https://www.drugs.com/pro/camcevi.html
[207] Drugs.com. FDA Approves Artesunate. Available from: https://www.drugs.com/newdrugs/fda-approves-artesunate-severe-malaria-5244.html
[208] Drugs.com. Dojolvi. Available from: https://www.drugs.com/dojolvi.html
[209] ConsultantPlus. List of psychotropic substances whose turnover in the Russian Federation is limited and for which certain control measures may be excluded in accordance with the legislation of the Russian Federation and international treaties of the Russian Federation (List III). Available from: https://www.consultant.ru/document/cons_doc_LAW_136206/99b9c00551ec8df9db44dea714007a 82d2595d3d/. Russia
[210] Drugs.com. Byfavo. Available from: https://www.drugs.com/mtm/byfavo.html
[211] Drugs.com. Lampit. Available from: https://www.drugs.com/lampit.html
[212] Drugs.com. Evrysdi. Available from: https://www.drugs.com/evrysdi.html
[213] Drugs.com. Viltepso. Available from: https://www.drugs.com/viltepso.html
[214] Drugs.com. Winlevi. Available from: https://www.drugs.com/winlevi.html

Somapacitan (Sogroya®) is approved as the first human growth hormone therapy for adults with its deficiency, binding to serum albumin, which slows its elimination[215].

Atoltivimab / maftivimab / odesivimab (Inmazeb®) is the first drug containing a fixed combination of three monoclonal antibodies directed against the glycoprotein of the Ebola virus[216]. Remdesivir (Veklury®) is approved for the treatment of COVID-19, which acts as an inhibitor of RNA-dependent RNA polymerase (a direct-acting antiviral agent), an enzyme necessary for the replication of a number of RNA viruses (ebolaviruses and coronaviruses)[217]. For the treatment of infection caused by the Ebola virus, a drug containing ansuvimab (Ebanga®) (a neutralizing antibody, was isolated from the blood of a person who survived an outbreak of the disease caused by the Ebola virus in 1995)[218] has also been approved.

Lonafarnib (Zokinvy®) (a synthetic tricyclic halogenated carboxamide with potential antineoplastic properties), a farnesyltransferase inhibitor, is approved as an oral medication to help prevent the accumulation of defective progerin or progerin-like protein in Hutchinson-Gilford progeria syndrome[219].

Lumasiran (Oxlumo®) (a double-stranded small interfering ribonucleic acid [siRNA]), is approved to reduce the level of the enzyme glycolate oxidase by targeting the messenger mRNA HAO1 in hepatocytes via RNA interference, resulting in a reduction in the amount of glyoxylate available, a substrate for oxalate formation[220].

Setmelanotide (Imcivree®) is approved for the treatment of a rare form of obesity. The compound binds to and activates MC 4 receptors in the paraventricular nucleus of the hypothalamus and in the lateral hypothalamic area—areas involved in appetite regulation. This action is believed to underlie its appetite-suppressing effects. In addition to reducing appetite, setmelanotide increases resting energy expenditure in both obese animals and humans [48–50]. Importantly, unlike some other MC 4 receptor agonists, setmelanotide does not cause an increase in heart rate or blood pressure[221].

Berotralstat (Orladeyo®) is approved for the prevention of hereditary angioedema, acts as an inhibitor of plasma kallikrein, which leads to the blockade of bradykinin release — a key biological peptide that contributes to swelling and pain[222].

Vibegron (Gemtesa®) is approved as a drug for the treatment of overactive bladder, acts as a selective β3-adrenergic receptor agonist (discovered in 1980; initially considered as a potential target for the treatment of obesity and diabetes [51]) located in the kidneys, urinary tract, and bladder[223].

2021

In 2021, a total of 94 drugs were approved, of which 65 were original (including 44 biologicals), 10 were new combinations, 1 was a generic drug, and 11 had a new dosage form or a new indication for use. The main categories of approved drugs were for the treatment of oncological and orphan diseases (26 drugs). In particular, ribociclib (Kisqali®; for the treatment of breast cancer)[224], tirzepatide (Mounjaro®; for the treatment of type 2 diabetes)[225], tebentafusp (Kimmtrak®; for the treatment of unresectable or metastatic uveal melanoma)[226], olutasidenib (Rezlidhia®; for the treatment of relapsed acute myeloid leukemia with IDH1 mutation)[227], anifrolumab (Saphnelo®; for the treatment of systemic lupus erythematosus)[228], aducanumab (Aduhelm®; the first anti-amyloid antibody for the treatment of Alzheimer's disease)[229] were approved (Fig. 10).

Vericiguat (Verquvo®) is approved as the first-in-class drug to reduce cardiovascular risks in patients with heart failure, acting as a direct stimulator

[215] Drugs.com. Sogroya. Available from: https://www.drugs.com/sogroya.html
[216] Drugs.com. Inmazeb. Available from: https://www.drugs.com/pro/inmazeb.html
[217] Drugs.com. Veklury. Available from: https://www.drugs.com/veklury.html
[218] Drugs.com. Ebanga. Available from: https://www.drugs.com/pro/ebanga.html
[219] Drugs.com. Zokinvy. Available from: https://www.drugs.com/zokinvy.html
[220] Drugs.com. Oxlumo. Available from: https://www.drugs.com/mtm/oxlumo.html
[221] Drugs.com. Imcivree. Available from: https://www.drugs.com/imcivree.html
[222] Drugs.com. Orladeyo. Available from: https://www.drugs.com/orladeyo.html
[223] Drugs.com. Gemtesa. Available from: https://www.drugs.com/gemtesa.html
[224] Drugs.com. Kisqali. Available from: https://www.drugs.com/kisqali.html
[225] Drugs.com. Mounjaro. Available from: https://www.drugs.com/mounjaro.html
[226] Drugs.com. Kimmtrak. Available from: https://www.drugs.com/kimmtrak.html
[227] Drugs.com. Rezlidhia. Available from: https://www.drugs.com/rezlidhia.html
[228] Drugs.com. Saphnelo. Available from: https://www.drugs.com/saphnelo.html
[229] Drugs.com. Aduhelm. Available from: https://www.drugs.com/aduhelm.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

of soluble guanylate cyclase, interacting with the β-subunit of its regulatory site[230].

Paliperidone palmitate (Invega Hafyera®) is approved for the treatment of Schizophrenia under a new brand name. This drug was originally approved in 2006 under the brand name Invega, in 2009 the indications were expanded (schizoaffective disorder) and an injectable form was approved, and in 2014 it became available for use by adolescents; in 2021, this drug was approved under a new formulation (Invega Hafyera®, extended-release suspension)[231].

Voclosporin (Lupkynis®) is approved as the first-in-class calcineurin inhibitor for the treatment of lupus nephritis, acting as an immunosuppressant and exerting an immunomodulatory effect on T-cells, stabilizing podocytes[232].

Evinacumab (Evkeeza®) is approved for the treatment of homozygous familial hypercholesterolemia[233]. This is the first-in-class drug, the mechanism of action of which is associated with the effect on angiopoietin-like protein 3, which slows down the work of enzymes involved in the breakdown of fats in the body [52].

Casimersen (Amondys 45™) is approved for the treatment of Duchenne muscular dystrophy[234], is an antisense phosphorodiamidate morpholino oligonucleotide for binding to exon 45 of the pre-mRNA of the Duchenne muscular dystrophy (*DMD*) gene, which prevents its exclusion into mature RNA before translation, which causes the production of an internally shortened dystrophin protein [53].

Fosdenopterin (Nulibry®) is approved to reduce the risk of death due to a rare genetic disorder known as molybdenum cofactor deficiency type A. It is a replacement drug for intravenous administration, a metabolic precursor of molybdopterin necessary for the enzymatic activity of sulfite oxidase, xanthine dehydrogenase/oxidase, and aldehyde oxidase[235].

The combination of serdexmethylphenidate (a prodrug of dexmethylphenidate) and dexmethylphenidate (Azstarys®) is approved for the treatment of attention deficit hyperactivity disorder in patients over 6 years of age[236]. Another drug for the treatment of this mental disorder is viloxazine (Qelbree®; extended-release form)[237], which also acts as a selective norepinephrine reuptake inhibitor and has been used as an antidepressant for more than 30 years (in immediate-release form). This is a racemic compound with two stereoisomers — the (S)-(–)-isomer is five times more pharmacologically active than the (R)-(+)-isomer — first used in 1974 [54].

Dasiglucagon (Zegalogue®) is the first glucagon product (approved for medical use in 1960) that comes in a ready-to-use aqueous formula. Like endogenous glucagon, dasiglucagon consists of 29 amino acids, but with 7 amino acid substitutions, which ensures its physical and chemical stability in an aqueous environment. It is intended for the relief of hypoglycemia; previously, drugs containing glucagon in the form for subcutaneous injections (in dimethyl sulfoxide) or powder for intranasal administration (approved in 2019) were approved for use for this indication[238].

The first-in-class antifungal drug — ibrexafungerp (triterpenoid) (Brexafemme®) —an inhibitor of glucan synthase and a blocker of the synthesis of 1,3-β-D-glucan of Candida fungi that cause vaginal candidiasis (potentially active against many pathogens of life-threatening fungal lesions) has been approved[239].

A new antiviral drug for the treatment of smallpox is brincidofovir (Tembexa®)[240], which is a prodrug of cidofovir (conjugated to a lipid molecule that facilitates penetration into the cell, in which cidofovir is phosphorylated, turning into an active diphosphate, acting as an acyclic nucleotide [incorporated into the viral DNA chain and stops the synthesis of viral DNA]). Currently, the drug is being investigated for activity against other dangerous viruses [55].

Semaglutide (Wegovy®) — a GLP-1RA in the form of injections is approved for weight loss[241].

[230] Drugs.com. Verquvo. Available from: https://www.drugs.com/verquvo.html
[231] Drugs.com. Invega Hafyera. Available from: https://www.drugs.com/invega-hafyera.html
[232] Drugs.com. Lupkynis. Available from: https://www.drugs.com/lupkynis.html
[233] Drugs.com. Evkeeza. Available from: https://www.drugs.com/evkeeza.html
[234] Drugs.com. Amondys 45. Available from: https://www.drugs.com/amondys-45.html
[235] Drugs.com. Nulibry. Available from: https://www.drugs.com/mtm/nulibry.html
[236] Drugs.com. Azstarys. Available from: https://www.drugs.com/azstarys.html
[237] Drugs.com. Qelbree. Available from: https://www.drugs.com/qelbree.html
[238] Drugs.com. Zegalogue. Available from: https://www.drugs.com/zegalogue.html
[239] Drugs.com. Brexafemme. Available from: https://www.drugs.com/brexafemme.html
[240] Drugs.com. Tembexa. Available from: https://www.drugs.com/tembexa.html
[241] Drugs.com. Wegovy. Available from: https://www.drugs.com/wegovy.html

Finerenone (Kerendia®) is approved as the first-in-class drug for the treatment of kidney diseases associated with T2DM, which is an oral non-steroidal antagonist of mineralocorticoid receptors containing the S810L mutation. Unlike eplerenone and spironolactone, it has less affinity for other steroid hormone receptors[242].

Another representative of the "first-in-class" drugs is approved for the treatment of chronic graft-versus-host disease — belumosudil (Rezurock®) — an inhibitor of serine / threonine kinase (Rho-associated coiled-coil containing protein kinase 2, ROCK2), also affects oxidative phosphorylation and angiogenesis[243].

Fexinidazole is a drug that continues the trend of forming new indications for known drugs (fexinidazole was first described in 1978). The drug has been approved for the treatment of African trypanosomiasis (sleeping sickness; the active metabolites in vivo are sulfoxide and sulfone) caused by *Trypanosoma brucei gambiense*[244]. Fexinidazole is less effective than nifurtimox in combination with eflornithine in severe cases of the disease, but it has the advantage that it can be taken orally (acoziborole is in clinical trials). This is the first drug in 30 years intended for the treatment of late-stage sleeping sickness.

Odevixibat (Bylvay®) is the first-in-class drug — a reversible, selective, low-molecular-weight inhibitor of the ileal sodium/bile cotransporter, which is responsible for the reabsorption of most bile acids in the distal ileum, which leads to a decrease in FXR (farnesoid X receptor) stimulation, reducing the inhibition of bile acid synthesis [56]. Bylvay® is indicated for the treatment of pruritus in people aged 3 months and older with progressive familial intrahepatic cholestasis[245].

A new combination (Twyneo®) containing a fixed dose of tretinoin (vitamin A derivative) / benzoyl peroxide (oxidizing agent) for the treatment of acne has been approved.

In the continuation of new drugs developed for enzyme replacement therapy, avalglucosidase α (Nexviazyme®)[246] has been approved — consists of the human enzyme α-acid glucosidase, which is conjugated with a pair of tetramannose glycans bis-mannose-6-phosphate. The substance binds to the cation-independent mannose-6-phosphate receptor located on skeletal muscles and enters the cell, where, penetrating into lysosomes, it undergoes proteolytic cleavage, subsequently acting as an enzyme for the treatment of glycogen storage disease type II (Pompe disease) [57].

The first-in-class inhibitor of hypoxia-inducible factor-2α (HIF2; binds to HIF-2α and, under hypoxia or impaired VHL protein function, blocks the formation of the HIF-2α-HIF-1β transcription complex, reduces transcription and expression of HIF-2α target genes) belzutifan (Welireg®) is approved for the treatment of renal cell carcinoma associated with von Hippel-Lindau disease[247] (extensive studies have indicated its effectiveness against Pachak-Zhuang syndrome with polycythemia and paragangliomas in adolescents [58]).

Also approved was the first-in-class selective κ-opioid receptor agonist difelikefalin (Korsuva®)[248], which acts as an analgesic (unlike pentazocine and phenazocine, it has no side effects associated with CNS effects [59]), activating these receptors on peripheral nerve endings (reduces the intensity of pain signal transmission) and immune system cells (reduces the release of pro-inflammatory nerve-sensitizing mediators, such as prostaglandins) [60, 61]. Indicated for the treatment of pruritus associated with chronic kidney disease.

Lonapegsomatropin (Skytrofa®), which is a somatotropin prodrug, has been approved for hormone replacement therapy in growth hormone deficiency[249].

Atogepant (Qulipta®) is approved for migraine prevention. It is a low molecular weight oral antagonist of the calcitonin gene-related peptide receptor (CGRP; blocks the binding of CGRP to the receptor, preventing its activation). Unlike 5-HT1 receptor agonists (triptans), its use does not cause vasoconstrictor effects[250].

Maralixibat chloride (Livmarli®) for the treatment

[242] Drugs.com. Kerendia. Available from: https://www.drugs.com/kerendia.html
[243] Drugs.com. Rezurock. Available from: https://www.drugs.com/rezurock.html
[244] Drugs.com. Fexinidazole. Available from: https://www.drugs.com/pro/fexinidazole.html
[245] Drugs.com. Bylvay. Available from: https://www.drugs.com/bylvay.html
[246] Drugs.com. Nexviazyme. Available from: https://www.drugs.com/mtm/nexviazyme.html
[247] Drugs.com. Welireg. Available from: https://www.drugs.com/welireg.html
[248] Drugs.com. Korsuva. Available from: https://www.drugs.com/korsuva.html
[249] Drugs.com. Skytrofa. Available from: https://www.drugs.com/skytrofa.html
[250] Drugs.com. Qulipta. Available from: https://www.drugs.com/qulipta.html

ОБЗОР
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of cholestatic pruritus in people with Alagille syndrome, acts as a reversible inhibitor of the apical sodium-dependent bile acid transporter (ASBT), reducing the reabsorption of bile acids (mainly salts) from the terminal ileum, which is accompanied by a decrease in itching[251].

Another "first-in-class" drug, avacopan (Tavneos®), is approved for the treatment of vasculitis associated with anti-neutrophil cytoplasmic autoantibodies, including granulomatosis with polyangiitis and microscopic polyangiitis[252]. It acts as a C5a complement receptor blocker for oral administration, and also suppresses neutrophil migration and activation [62].

The allogeneic processed thymus tissue product (Rethymic®)[253] has been approved for restoring immunity in patients with athymia (an extremely rare disease in which children are born without a thymus, leading to profound immunodeficiency). Recipient T-cell precursors from the bone marrow migrate to the implanted allogeneic thymus tissue sites, where they develop into native immunocompetent T-cells [63].

Varenicline (Tyrvaya®) was originally developed as a cytisine analogue and used to facilitate smoking cessation, as both compounds are full or partial agonists of various subtypes of nicotinic acetylcholine receptors (varenicline exhibits full agonism at α7 nicotinic acetylcholine receptors and is a partial agonist of α4β2, α3β4 and α6β2 subtypes)[254]. Their use, unlike nicotine, causes a smaller dopamine release effect and at the same time prevents the effects of nicotine on these receptors, provoking and stimulating the mesolimbic dopamine system [64]. This is similar to the action of buprenorphine in the treatment of opioid addiction. The implementation of varenicline as a drug for the treatment of nicotine addiction ceased in 2006, and in 2021 it was approved in the form of a nasal spray for the treatment of dry eye syndrome, the mechanism of action is associated with a specific irritating effect of the compound on the endings of the vagus nerve on the mucous membrane of the nasal sinuses, which causes intense lacrimation.

Ropeginterferon α-2b (Besremi®) is approved as a "first-in-class" drug for the treatment of polycythemia vera[255]. It is an interferon (IFN) α-2b (recombinant) covalently linked to monomethoxypolyethylene glycol (mPEG), and exerts cellular effects in the bone marrow as a result of binding to the transmembrane IFNα receptor, triggering a cascade of downstream signals through kinase activation, affecting the expression of individual genes [65].

Another first-in-class drug of 2021 was vosoritide (Voxzogo®) for the treatment of achondroplasia (a congenital disease resulting from a missense mutation in the fibroblast growth factor receptor 3 gene [*FGFR3*], leading to increased function that negatively regulates endochondral bone growth)[256]. Under normal conditions, FGFR3 is expressed both during embryonic (promotes proliferation) and postnatal (suppresses growth during puberty) development. Vosoritide is an analogue (with a longer duration of action) of C-type natriuretic peptide (CNP) — a signaling molecule that is primarily responsible for stimulating chondrocytes and long bone growth. Binding of CNP (or vosoritide) to its corresponding natriuretic peptide B receptor (NPR-B) leads to inhibition of the MAPK / ERK pathway by blocking RAF-1, which promotes chondrocyte proliferation and differentiation. This activity serves to counteract the downstream signal resulting from FGFR3 and its resulting effect on bone growth [66].

Initially, rapamycin was developed as an antifungal agent, but after the discovery of its immunosuppressive and antiproliferative effects (1994), its use was directed towards influencing immunity (immunosuppression in transplantation) and cancer (suppression of proliferation) [67]. In 2021, sirolimus (Fyarro®) was approved for the treatment of malignant perivascular epithelioid cell tumor (in 2022 it was approved for the treatment of angiofibromas)[257].

Efgartigimod-α (Vyvgart®) (antibody fragment) is the first-in-class neonatal Fc receptor blocker, preventing the recirculation of immunoglobulin G back into the blood, reducing its total amount and preventing the degradation of acetylcholine receptors by autoantibodies that cause myasthenia gravis[258].

[251] Drugs.com. Livmarli. Available from: https://www.drugs.com/livmarli.html
[252] Drugs.com. Tavneos. Available from: https://www.drugs.com/tavneos.html
[253] Drugs.com. Rethymic. Available from: https://www.drugs.com/pro/rethymic.html
[254] Drugs.com. Tyrvaya. Available from: https://www.drugs.com/tyrvaya.html
[255] Drugs.com. Besremi. Available from: https://www.drugs.com/besremi.html
[256] Drugs.com. Voxzogo. Available from: https://www.drugs.com/voxzogo.html
[257] Drugs.com. Fyarro. Available from: https://www.drugs.com/mtm/fyarro.html
[258] Drugs.com. Vyvgart. Available from: https://www.drugs.com/vyvgart.html

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Cabotegravir (Apretude®) is approved for the treatment of HIV / AIDS as a drug with antiretroviral activity[259], is an integrase strand transfer inhibitor, i.e. blocks the HIV integrase enzyme, thereby preventing the integration of its genome into human cell DNA; structurally similar to dolutegravir, which was approved in 2013.

Inclisiran (Leqvio®)[260] is an siRNA that acts as a proprotein convertase inhibitor, specifically inhibiting the translation of the PCSK9 protein (a serine protease produced and secreted by the liver, the binding and action of which on low-density lipoprotein receptors [LDL] leads to their increased lysosomal degradation in hepatocytes, resulting in an increase in circulating LDL cholesterol levels, and inhibition of this process leads to a decrease in LDL) [68] — the first-in-class drug for the treatment of high LDL cholesterol in people with atherosclerotic cardiovascular disease, as well as with heterozygous familial hypercholesterolemia.

Levoketoconazole (Recorlev®)[261] is the levorotatory enantiomer of ketoconazole (an antifungal agent, an imidazole derivative, first synthesized in 1977), an inhibitor of the enzymes CYP11B1 (11β-hydroxylase), CYP17A1 (17α-hydroxylase/17,20-lyase) and CYP21A2 (21-hydroxylase), CYP11A1 (cholesterol side-chain cleavage enzyme), CYP51A1 (lanosterol-14α-demethylase); inhibits the biosynthesis of glucocorticoids, reducing their level, which determines its use in Cushing's syndrome [69].

2022

In 2022, approval was received for 80 drugs, including 37 original drugs (27 of them is biologicals), 4 new combinations, 4 reproduced drugs, as well as 20 drugs in a new dosage form or with new indications for use. These drugs cover a wide range of medical conditions, including cancer, dermatological diseases, rare diseases, and autoimmune disorders. Notably, 31% of the drugs approved in 2022 are intended for the treatment of various types of cancer, including non-Hodgkin's lymphoma, NSCLC, and relapsed myeloid leukemia. 14% of approved drugs were intended for the treatment of neurological diseases (including amyotrophic lateral sclerosis and transthyretin amyloid polyneuropathy). In particular, tebentafusp (Kimmtrak®; for the treatment of unresectable or metastatic uveal melanoma)[262], mosunetumab (Lunsumio®; for the treatment of relapsed or refractory follicular lymphoma)[263], olutasidenib (Rezlidhia®; for the treatment of relapsed acute myeloid leukemia with IDH1 mutation)[264], tirzepatide (Mounjaro®; injectable drug for the treatment of type 2 diabetes)[265], deucravacitinib (Sotyktu®; for the treatment of psoriasis)[266] were approved (Fig. 11).

Tebentafusp (Kimmtrak®) is an anticancer drug (therapy for inoperable or metastatic uveal melanoma), the first-in-class bispecific gp100-peptide-HLA-directed activator of cluster of differentiation (CD) 3+ T-cells for intravenous infusions[267].

Faricimab (Vabysmo®) is approved for the treatment of neovascular age-related macular degeneration and diabetic macular edema[268], and is the first bispecific monoclonal antibody to vascular endothelial growth factor and angiopoietin 2. By blocking the action of these two growth factors, faricimab reduces the migration and replication of endothelial cells, inhibiting angiogenesis [70].

Sutimlimab (Enjaymo®) is the first-in-class monoclonal antibody for the treatment of adults with cold agglutinin disease, which, by acting on the C1s enzyme and inhibiting its enzymatic spread along the classical complement pathway, prevents the formation of the C3-convertase enzyme and complement-enhanced activation of autoimmune B cells[269].

Mitapivat (Pyrukynd®) is approved as the first-in-class drug for the treatment of hemolytic anemia[270], acting as a pyruvate kinase activator, binding to it and, by activating it, enhances the activity of the glycolytic pathway, increasing the level of adenosine triphosphate (ATP) and reducing the level of 2,3-diphosphoglycerate (2,3-DPG). Mutations in pyruvate kinase cause pyruvate

[259] Drugs.com. Apretude. Available from: https://www.drugs.com/apretude.html
[260] Drugs.com. Leqvio. Available from: https://www.drugs.com/leqvio.html
[261] Drugs.com. Recorlev. Available from: https://www.drugs.com/recorlev.html
[262] Drugs.com. Kimmtrak. Available from: https://www.drugs.com/kimmtrak.html
[263] Drugs.com. Lunsumio. Available from: https://www.drugs.com/lunsumio.html
[264] Drugs.com. Rezlidhia. Available from: https://www.drugs.com/rezlidhia.html
[265] Drugs.com. Mounjaro. Available from: https://www.drugs.com/mounjaro.html
[266] Drugs.com. Sotyktu. Available from: https://www.drugs.com/sotyktu.html
[267] Drugs.com. Kimmtrak. Available from: https://www.drugs.com/kimmtrak.html
[268] Drugs.com. Vabysmo. Available from: https://www.drugs.com/vabysmo.html
[269] Drugs.com. Enjaymo. Available from: https://www.drugs.com/enjaymo.html
[270] Drugs.com. Pyrukynd. Available from: https://www.drugs.com/pyrukynd.html

ОБЗОР
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kinase deficiency, which prevents adequate glycolysis of red blood cells (RBCs), leading to the accumulation of the glycolysis intermediate 2,3-DPG and a deficiency of the pyruvate kinase product ATP [71].

Dexmedetomidine (Igalmi®) is approved for sedation (approved in veterinary practice since 2006) in acute agitation associated with schizophrenia or bipolar disorder, available as a solution for injection or intravenous administration, as well as in the form of a buccal or sublingual film[271]. It acts similarly to clonidine (8 times more selective), as an α2-adrenergic receptor agonist in certain parts of the brain, without having a depressant effect on respiration and more closely mimicking natural sleep, and to a lesser extent causing amnesia [72].

Mavacamten (Camzyos®) is approved as the first-in-class drug for the treatment of obstructive hypertrophic cardiomyopathy, affecting sarcomere hypercontractility, which is one of the characteristics of hypertrophic cardiomyopathy, and also inhibits excessive formation of myosin and actin cross-bridges, shifting the overall myosin population towards an energy-saving, recruitable, super-relaxed state[272].

Tirzepatide (Mounjaro®) is the first-in-class dual agonist of incretin system receptors (glucose-dependent insulinotropic polypeptide and glucagon-like peptide-1) — a drug used to treat T2DM and for weight loss (since 2023) and moderate to severe obstructive sleep apnea (since 2024)[273].

A new triple combination (Voquezna Triple Pak®) has been approved for the treatment of *Helicobacter pylori* infection, consisting of a potassium-competitive acid transporter blocker vonoprazan, amoxicillin (β-lactam antibiotic) and clarithromycin (macrolide antibiotic)[274].

Vutrisiran (Amvuttra®) is approved as an orphan drug for the treatment of polyneuropathy of hereditary transthyretin-mediated amyloidosis (hATTR) in adults. It is a double-stranded small interfering RNA that prevents the expression of the transthyretin gene (*TTR*; a serum protein produced in the liver, the main function of which is to transport vitamin A and thyroxine). Rare mutations in the transthyretin gene lead to the accumulation of large amyloid deposits of misfolded transthyretin molecules, most noticeably in the peripheral nerves and heart, which provokes the development of polyneuropathy, progressing to cardiomyopathy[275].

Betibeglogene autotemcel (Zynteglo®) is approved for gene therapy for β-thalassemia in people who do not have the β0/β0 genotype and who are suitable for hematopoietic stem cell transplantation (HSCT) but lack a related HLA-matched HSCT donor. Betibeglogene autotemcel is produced individually for each recipient from stem cells collected from their blood, administered as an autologous intravenous infusion, the dose depends on the recipient's body weight; before administration, the recipient undergoes preliminary chemotherapy to cleanse the bone marrow of cells[276].

Olipudase-α (Xenpozyme®) is approved as the first-in-class enzyme replacement therapy for the treatment of acid sphingomyelinase deficiency type A/B or type B (Niemann-Pick disease) not associated with the CNS[277].

Spesolimab (Spevigo®) is approved as the first-in-class drug for the treatment of generalized pustular psoriasis, is a monoclonal antibody that acts as an IL-36 receptor antagonist[278].

Daxxibotulinumtoxin A (Daxxify®) is approved for the temporary improvement in the appearance of moderate to severe glabellar lines (wrinkles between the eyebrows)[279], later (in 2024) letibotulinumtoxin A was approved for use for the same purpose, and earlier (in 2010) botulinum toxin was approved for the prevention of chronic migraine (intramuscular injections) and, in 2016 (abobotulinumtoxin A), for the treatment of spasticity of the lower extremities in children aged two years and older. Botulinum toxin exerts its effect by cleaving key proteins required for nerve activation. After binding to the nerve ending, the toxin enters the vesicle via receptor-mediated endocytosis, from which it is released into the cytoplasm, where the toxin cleaves SNARE proteins (proteins that mediate the fusion of vesicles with their target membrane-bound compartments) and

[271] Drugs.com. Igalmi (buccal/sublingual). Available from: https://www.drugs.com/mtm/igalmi-buccal-sublingual.html
[272] Drugs.com. Camzyos. Available from: https://www.drugs.com/camzyos.html
[273] Drugs.com. Mounjaro. Available from: https://www.drugs.com/mounjaro.html
[274] Drugs.com. Voquezna Triple Pak. Available from: https://www.drugs.com/voquezna-triple-pak.html
[275] Drugs.com. Amvuttra. Available from: https://www.drugs.com/amvuttra.html
[276] Drugs.com. Zynteglo. Available from: https://www.drugs.com/zynteglo.html
[277] Drugs.com. Xenpozyme. Available from: https://www.drugs.com/xenpozyme.html
[278] Drugs.com. Spevigo. Available from: https://www.drugs.com/spevigo.html
[279] Drugs.com. Daxxify. Available from: https://www.drugs.com/daxxify.html

acetylcholine vesicles cannot bind to the intracellular cell membrane, preventing the cell from releasing neurotransmitter vesicles. This stops nerve signaling, resulting in flaccid paralysis. This blockade is slowly removed as the toxin loses activity and SNARE proteins are slowly regenerated by the affected cell. The first use of botulinum toxin A dates back to 1977, it was administered to patients with strabismus, and the first FDA approval was obtained in 1989 for the treatment of strabismus and blepharospasm in adults.

Deucravacitinib (Sotyktu®), a first-in-class drug, a highly selective allosteric inhibitor of non-receptor tyrosine-protein kinase 2 (TYK2) approved for the treatment of moderate to severe plaque psoriasis[280]. It is noteworthy that the molecule of the active substance contains methylamide, in which all three hydrogen atoms are replaced by deuterium, which is a promising trend in modern medicinal chemistry [73].

Elivaldogene autotemcel (Skysona®) is a gene therapy (single; autologous hematopoietic stem cell therapy in which stem cells are mobilized and collected from the patient and genetically modified to transfer a functional copy of the *ABCD1* gene using a lentiviral vector) for the treatment of cerebral adrenoleukodystrophy (cerebral adrenoleukodystrophy is caused by a mutation in the *ABCD1* gene on the X chromosome, which encodes the ALD protein, which helps transport very long chain fatty acids (VLCFA) into peroxisomes for degradation, when the *ABCD1* gene is dysfunctional, they degrade incorrectly and accumulate abnormally in the blood and CNS, penetrate the BBB and are incorporated into white matter, damaging myelin)[281].

Omidenepag isopropyl (Omlonti®) is approved for the treatment of glaucoma and high intraocular pressure, is a prodrug that, upon hydrolysis, is converted to the active metabolite omidenepag, a selective prostaglandin E2 receptor agonist[282].

Teplizumab (Tzield®) is a first-in-class drug that is a humanized monoclonal antibody (mAb) targeting the CD3+ antigen co-expressed with the T-cell receptor on the surface of T lymphocytes, which is the first approved treatment shown to delay the onset of stage 3 type 1 diabetes in people with stage 2 type 1 diabetes[283]. The Fc region of the mAb was designed not to interact with the Fc receptor to avoid side effects (e.g., cytokine release) associated with an intact Fc. The mechanisms of action of teplizumab appear to include weak agonistic activity in signaling through the CD3+ T-cell receptor complex associated with the development of anergy, unresponsiveness, and/or apoptosis, especially of unwanted activated effector T lymphocytes. The mechanism may involve partial agonistic signaling and deactivation of autoreactive T lymphocytes of pancreatic β-cells, leading to an increase in the proportion of regulatory T-cells and exhausted CD8+ T-cells in the peripheral blood [74]. It is important to note that this is the only drug for use as a prophylactic rather than a therapeutic agent in people at high risk of diabetic ketoacidosis.

Etranacogene dezaparvovec (Hemgenix®) is another gene therapy (also has breakthrough status) for the treatment of hemophilia B (absence or insufficient levels of blood clotting factor IX). It is a vector gene therapy based on an adeno-associated virus carrying the blood clotting factor IX gene. In 2022, this therapy was the most expensive in the world[284].

Another gene therapy based on an adenovirus vector is approved for the treatment of non-muscle-invasive bladder cancer unresponsive to Bacillus Calmette-Guerin with carcinoma *in situ* with or without papillary tumors — nadofaragene firadenovec (Adstiladrin®); created using an excipient (Syn-3) that facilitates gene transfer through the urothelium and promotes transduction of the human *IFNα2b* gene (induces apoptosis in human bladder cancer cells unresponsive to BCG by inducing the production of autocrine TNFα associated with apoptosis-inducing ligand). Localized expression of this gene causes antitumor effects[285].

The herbal preparation anacaulase-bcdb (NexoBrid®) has been approved for the removal of eschar in adults with deep partial and/or full thickness thermal burns[286]. The drug is a mixture of proteolytic enzymes extracted from the stems of pineapple plants (*Ananas comosus* [L.] Merr.). It mainly consists (80–95% by weight) of proteins such as stem

[280] Drugs.com. Sotyktu. Available from: https://www.drugs.com/sotyktu.html
[281] Drugs.com. Skysona. Available from: https://www.drugs.com/skysona.html
[282] Drugs.com. Omlonti. Available from: https://www.drugs.com/omlonti.html
[283] Drugs.com. Tzield. Available from: https://www.drugs.com/tzield.html
[284] Drugs.com. Hemgenix. Available from: https://www.drugs.com/hemgenix.html
[285] Drugs.com. Adstiladrin. Available from: https://www.drugs.com/adstiladrin.html
[286] Drugs.com. Nexobrid. Available from: https://www.drugs.com/pro/nexobrid.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

bromelain, ananain, jacalin-like lectin, bromelain inhibitors and phytocystatin inhibitor, as well as saccharides, both free monosaccharides and N-linked glycan of stem bromelain and low molecular weight metabolites [75].

A new form of vigabatrin (Vigpoder®; developed in the 1980s, first approved for medical use since 2009) — a solution for oral administration[287] (in 2024, the ready-made solution is approved for use in children from 1 month) is approved for the treatment of patients with infantile spasms. Vigabatrin is an inhibitor of GABA-AT aminotransferase: its administration leads to an increase in GABA levels in the brain.

2023

In 2023, the FDA approved 111 drugs, 55 of which were new, which corresponds to the average for the last 5 years. The share of biologicals exceeded the 40% threshold in 2023 — to date, this is a record value for this group of drugs. The main categories of approved drugs included the following:

- monoclonal antibodies: 12 approved drugs, which is a record for this category;
- peptides and oligonucleotides: 9 approved drugs, including 5 peptides and 4 oligonucleotides;
- biologicals: 17 new biologicals, which corresponds to the average for recent years.

The drugs registered in 2023 were intended for the treatment of a wide range of diseases, including orphan diseases, as well as neurological disorders and oncological diseases. In the period under study, the largest number of registrations for the treatment of oncological diseases occurred in 2023 (Fig. 12).

In particular, the following drugs were approved: lecanemab (Leqembi®; for the treatment of Alzheimer's disease)[288], pirtobrutinib (Jaypirca®; for the treatment of relapsed or refractory mantle cell lymphoma)[289], elacestrant (Orserdu®; for the treatment of estrogen receptor-positive breast cancer)[290], peguigalsidase α (Elfabrio®; for the treatment of Fabry disease)[291]. During 2023, several drugs were approved that should be emphasized due to their impact on the creation and approval process.

Lovotibeglogene autotemcel (Lyfgenia®), a gene therapy drug for sickle cell anemia, is surprising not only for its approach to gene modification of the patient's own cells with their subsequent return to the body, but also for its agreed cost[292].

The approval of tirzepatide (Mounjaro® in 2022 and Zepbound® in 2023)[293, 294] caused excitement throughout the GLP-1 market, while the first dual agonist of key incretin receptors may significantly affect the effectiveness of therapy for many patients. Cantharidin, being a well-known chemical substance, the use of which has historically been reckless (as an aphrodisiac) due to its high toxicity, has been approved as a remedy for molluscum contagiosum (Ycanth®)[295]. Lotilaner 0.25% ophthalmic solution (Xdemvy®) for the treatment of demodecosis blepharitis is widespread in veterinary medicine[296].

A drug containing sildenafil citrate (Liqrev®) is registered as a drug for the treatment of pulmonary hypertension, which is symbolic, given the history of its creation and use[297].

The combination of hyaluronic acid and lidocaine (Skinvive by Juvéderm®) is approved for reducing the severity of wrinkles on the face[298], which can be considered a step towards expanding the pharmaceutical market or accelerating its expansion into the field of aesthetic medicine.

New gliflozins have been approved for the treatment of T2DM (bexagliflozin; Brenzavvy®)[299] and heart failure (sotagliflozin; Inpefa®)[300]. The first drug (donaisel; Lantidra®) for cell therapy of type 1 diabetes has appeared on the pharmaceutical market[301], which is an allogeneic (donor) cell therapy of pancreatic islets

[287] Drugs.com. Vigpoder. Available from: https://www.drugs.com/vigpoder.html
[288] Drugs.com. Leqembi. Available from: https://www.drugs.com/leqembi.html
[289] Drugs.com. Jaypirca. Available from: https://www.drugs.com/jaypirca.html
[290] Drugs.com. Orserdu. Available from: https://www.drugs.com/orserdu.html
[291] Drugs.com. Elfabrio. Available from: https://www.drugs.com/elfabrio.html
[292] Drugs.com. Lyfgenia. Available from: https://www.drugs.com/lyfgenia.html
[293] Drugs.com. Mounjaro. Available from: https://www.drugs.com/mounjaro.html
[294] Drugs.com. Zepbound. Available from: https://www.drugs.com/zepbound.html
[295] Drugs.com. Ycanth. Available from: https://www.drugs.com/ycanth.html
[296] Drugs.com. Xdemvy. Available from: https://www.drugs.com/xdemvy.html
[297] Drugs.com. Liqrev. Available from: https://www.drugs.com/liqrev.html
[298] Drugs.com. Skinvive. Available from: https://www.drugs.com/skinvive.html
[299] Drugs.com. Brenzavvy. Available from: https://www.drugs.com/brenzavvy.html
[300] Drugs.com. Inpefa. Available from: https://www.drugs.com/inpefa.html
[301] Drugs.com. Lantidra. Available from: https://www.drugs.com/lantidra.html

obtained from a donor, and which is administered once into the portal vein of the liver against the background of preliminary immunosuppression.

Nodosiran (Rivfloza®) is another product (patisiran, govosiran, lumasiran, inclisiran were previously approved) created on the basis of siRNA (selective "silencing" of genes necessary for the synthesis of unnecessary / defective proteins; for the description of this mechanism, scientists Andrew Fire and Craig Mello received the Nobel Prize in 2006) for the treatment of primary hyperoxaluria type 1[302].

A drug containing eflornithine (Iwilfin®; ornithine decarboxylase inhibitor) has been approved for the treatment of neuroblastoma[303]. It has been developed as an antitumor agent since the 1970s, but until 2023 it was used for hirsutism and African trypanosomiasis [77].

Cyclosporine (Vevye®) has been approved for the treatment of dry eye syndrome. This compound has been used for medical purposes for more than 40 years (since 1983), mainly for the treatment and prevention of graft-versus-host disease, treatment of rheumatoid arthritis, psoriasis, nummular keratitis after adenovirus keratoconjunctivitis, acute severe ulcerative colitis[304].

Colchicine (Lodoco®) has been approved to reduce cardiovascular risk in people with atherosclerosis or recent myocardial infarction; previously (since 1961), its medical use was limited to anti-gout properties. Colchicine was most effective in combination therapy with lipid-lowering and anti-inflammatory drugs[305]. The mechanism of this effect of colchicine is unknown.

Delandistrogene moxeparvovec (Elevidys®) is a gene therapy for children with Duchenne muscular dystrophy, which works by delivering a gene that is necessary for the production of microdystrophin, a shortened protein (138 kDa compared to the dystrophin protein of normal muscle cells weighing 427 kDa), which contains selected domains of the dystrophin protein present in normal muscle cells[306].

Somatrogon (Ngenla®) is approved for the treatment of children with growth retardation due to endogenous growth hormone deficiency, is a glycosylated protein created from human growth hormone and a small part of human chorionic gonadotropin[307].

Valoctocogene roxaparvovec (Roctavian®) is approved as a gene therapy that uses adeno-associated virus 5, which carries the human coagulation factor VIII (antihemophilic globulin) gene, along with a human liver-specific promoter that stimulates translation in hepatocytes, rather than in endothelial and sinusoidal liver cells, where coagulation factor VIII is normally synthesized[308].

Lotilaner ectoparasiticidal (Xdemvy®) is an antiparasitic drug, the first in its class for the treatment of blepharitis (inflammation of the eyelid) caused by Demodex (Demodex mite) infection. It is used in the form of eye drops, acts as an inhibitor of chloride channels activated by GABA in ticks[309].

Zuranolone (Zurzuvae®) is approved for the treatment of postpartum depression, inhibits a pregnane neurosteroid, a positive allosteric modulator of the GABAA receptor[310].

Avacincaptad pegol (Izervay®) is approved for the treatment of age-related macular degeneration — an RNA aptamer covalently linked to a branched polyethylene glycol molecule, an inhibitor of complement C5 (cleaved into C5a and C5b, and this is the last stage of the complement cascade, where a membrane-attacking complex (MAC) is formed, causing cell death) based on oligonucleotides[311]. By inhibiting the cleavage of complement C5, avacincaptad pegol can weaken inflammatory processes, thereby slowing down damage and degeneration of retinal cells [78].

Poselimab (Veopoz®) (first in class) is a recombinant human IgG4 monoclonal antibody (directed against the terminal complement protein C5, inhibits terminal complement activation by blocking the cleavage of C5 into C5a (anaphylatoxin) and C5b, thereby suppressing the formation of the MAC C5b-C9, which mediates cell lysis.), approved for the treatment of protein-losing enteropathy caused by CD55 deficiency (CHAPLE disease; complement hyperactivation), a complement inhibitor[312].

[302] Drugs.com. Rivfloza. Available from: https://www.drugs.com/rivfloza.html
[303] Drugs.com. Iwilfin. Available from: https://www.drugs.com/iwilfin.html
[304] Drugs.com. Vevye. Available from: https://www.drugs.com/vevye.html
[305] Drugs.com. Lodoco. Available from: https://www.drugs.com/lodoco.html
[306] Drugs.com. Eevidys. Available from: https://www.drugs.com/elevidys.html
[307] Drugs.com. Ngenla. Available from: https://www.drugs.com/ngenla.html
[308] Drugs.com. Roctavian. Available from: https://www.drugs.com/roctavian.html
[309] Drugs.com. Xdemvy. Available from: https://www.drugs.com/xdemvy.html
[310] Drugs.com. Zurzuvae. Available from: https://www.drugs.com/zurzuvae.html
[311] Drugs.com. Izervay. Available from: https://www.drugs.com/izervay.html
[312] Drugs.com. Veopoz. Available from: https://www.drugs.com/veopoz.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

A	Pancrelipase Taliglucerase Alfa Teduglutide Crofelemer Linagliptin and Metformin Hydrochloride Lorcaserin Sodium Picosulfate, Magnesium Oxide, and Citric Acid Phentermine and Topiramate Linaclotide Cysteamine Hydrochloride
B	Peginesatide Fibrin Sealant Apixaban
C	Icosapent Ethyl Epinephrine Lomitapide
D	Tazarotene
G	Testosterone Mifepristone Avanafil Mirabegron
H	Prednisolone Pasireotide
J	Meningococcal C and Y, Haemophilus influenzae B, Tetanus Toxoid Conjugate Vaccine Influenza Virus Vaccine Inactivated Raxibacumab Varicella Zoster Immune Globulin Intravenous Immunoglobulin Cobicistat, Elvitegravir, Emtricitabine, and Tenofovir Bedaquiline
L	Pertuzumab Ziv-Aflibercept Filgrastim Ingenol Mebutate Mitomycin Omacetaxine Melesuccinate Axitinib Vismodegib Carfilzomib Vincristine Sulfate Liposome Enzalutamide Bosutinib Teriflunomide Regorafenib Tofacitinib Cabozantinib Ponatinib
M	Alendronate
N	Fentanyl Methylphenidate Perampanel Loxapine
P	Invermectin
R	Lucinactant Ciclesonide Beclomethasone Dipropionate Ivacaftor Azelastine and Fluticasone Aclidinium Bromide
S	Ocriplasmin Tafluprost
V	Glucarpidase Florbetapir F-18

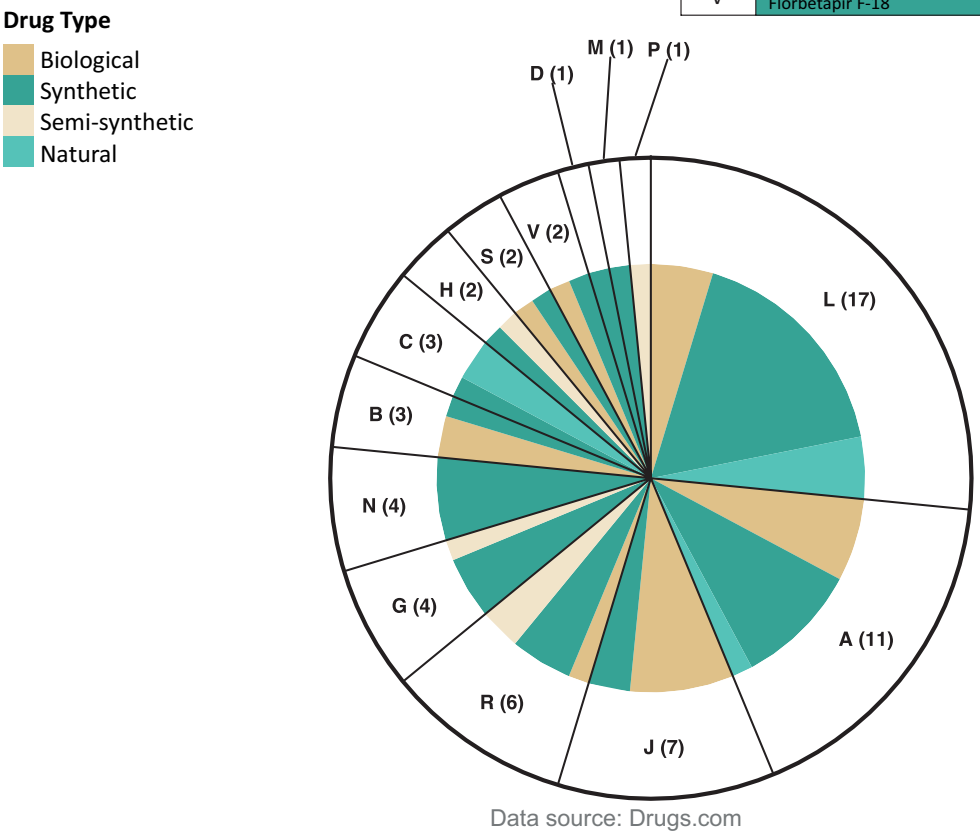
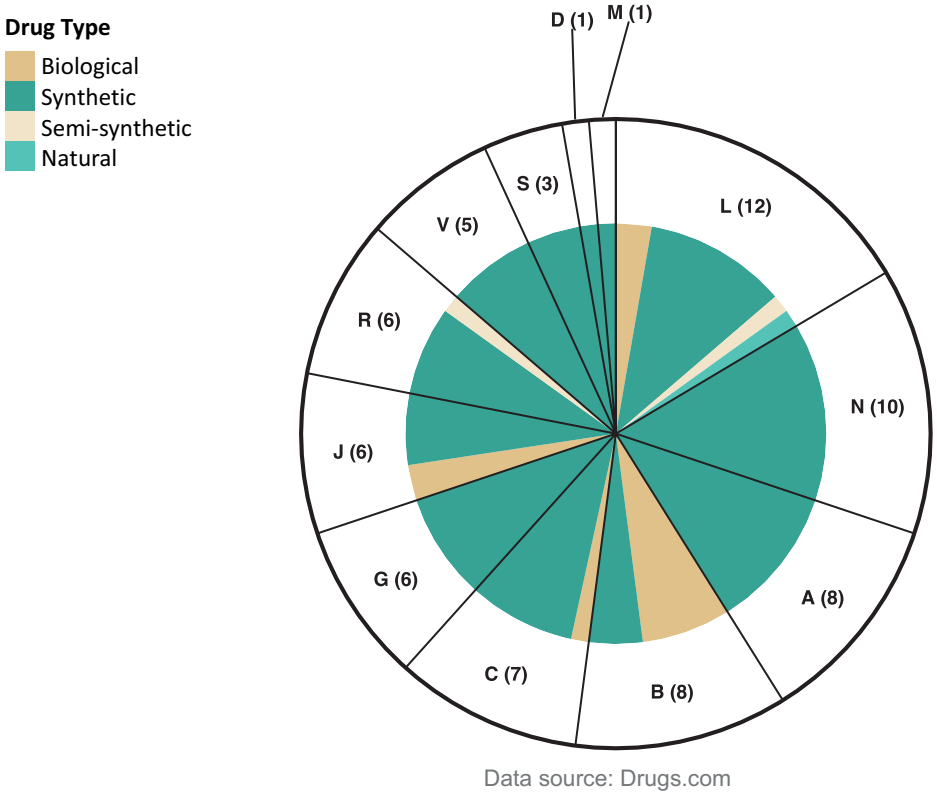


Figure 1 – FDA Approvals of Original Drugs in 2012.
Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types – biological, synthetic, semi-synthetic, or of natural origin.

A	Alogliptin Alogliptin and Metformin Alogliptin and Pioglitazone Mesalamine Glycerol Phenylbutyrate Canagliflozin Doxylamine and Pyridoxine Cysteamine Bitartrate
B	Pooled Plasma (Pooled) Prothrombin Complex Concentrate, Human Coagulation Factor IX, Recombinant Turoctocog Alfa Coagulation Factor XIII A-Subunit, Recombinant Ferric Carboxymaltose Clinolipid Treprostinil
C	Mipomersen Atorvastatin and Ezetimibe Nimodipine Enalapril Maleate Riociguat Macitentan Polidocanol
D	Luliconazole
G	Levonorgestrel Oxybutynin Ospemifene Levonorgestrel/Ethinyl Estradiol and Ethinyl Estradiol Ethinyl Estradiol and Norethindrone, Ethinyl Estradiol and Ferrous Fumarate Bazedoxifene and Conjugated Estrogens
J	Tobramycin Influenza Virus Vaccine, Inactivated Acyclovir Dolutegravir Simeprevir Sofosbuvir
L	Golimumab Obinutuzumab Tacrolimus Ado-trastuzumab Pomalidomide Dimethyl Fumarate Dabrafenib Trametinib Afatinib Mechlorethamine Methotrexate Ibrutinib
M	Diclofenac
N	Sumatriptan Aripiprazole Buprenorphine and Naloxone Paroxetine Mesylate Бупренорфин и Buprenorphine and Naloxone Desvenlafaxine Levomilnacipran Topiramate Vortioxetine Eslicarbazepine Acetate
R	Budesonide Chlorpheniramine and Hydrocodone Carbinoxamine Fluticasone and Vilanterol Hydrocodone Umeclidinium Bromide and Vilanterol
S	Bromfenac Brimonidine and Brinzolamide Brimonidine
V	Tilmanocept Gadoterate Meglumine Radium-223 Dichloride Flutemetamol F-18 Sucroferric Oxyhydroxide



Data source: Drugs.com

Figure 2 – FDA Approvals of Original Drugs in 2013.

Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic, or of natural origin.

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

A	Elosulfase Alfa Metreleptin Albiglutide Human Insulin Dulaglutide Liraglutide Dapagliflozin Empagliflozin Canagliflozin and Metformin Eliglustat Naloxegol Netupitant and Palonosetron Dapagliflozin and Metformin Hydrochloride
B	Coagulation Factor IX, Recombinant Antihemophilic Factor, Recombinant C1-Esterase Inhibitor, Recombinant Recombinant Antihemophilic Factor Vorapaxar Amino Acids, Electrolytes, Dextrose and Lipids
C	Omega-3-Acid Ethyl Esters Propranolol Hydrochloride Sotalol Hydrochloride
D	Efinaconazole Tavaborole Fluocinolone Acetonide Pirfenidone Benzoyl Peroxide and Clindamycin Phosphate
G	Testosterone Undecanoate Testosterone Ethinyl Estradiol and Norelgestromin
H	Pasireotide
J	Meningococcal Group B Vaccine Tobramycin 9-Valent Human Papillomavirus Vaccine, Recombinant Immunoglobulin and Hyaluronidase Dalbavancin Tedizolid Phosphate Doxycycline Hyclate Oritavancin Abacavir, Dolutegravir and Lamivudine Elvitegravir Ledipasvir and Sofosbuvir Ombitasvir/Paritaprevir/Ritonavir with Dasabuvir Ceftolozane and Tazobactam Peramivir
L	Ramucirumab Siltuximab Vedolizumab Peginterferon Beta-1a Pembrolizumab Alemtuzumab Blinatumomab Nivolumab Apremilast Nintedanib Mercaptopurine Ceritinib Belinostat Methotrexate Idelalisib Olaparib
M	Sodium Hyaluronate Indomethacin Dantrolene Diclofenac Sodium
N	Tasimelteon Droxidola Acetaminophen and Oxycodone Hydrochloride Topiramate Buprenorphine and Naloxone Naloxone and Oxycodone Suvorexant Bupropion and Naltrexone Donepezil and Memantine
P	Ivermectin Miltefosine
R	Diphenhydramine Hydrochloride and Naproxen Sodium Umeclidinium Phenylephrine Hydrochloride Fluticasone Propionate Olodaterol Fluticasone Furoate Hydrocodone Bitartrate
S	Ketorolac and Phenylephrine Finafloxacin
V	Ragweed Pollen Allergen Extract Florbetaben F18 Naloxone Hydrochloride Ferric Citrate Cobicistat Lipid Microspheres with Sulfur Hexafluoride

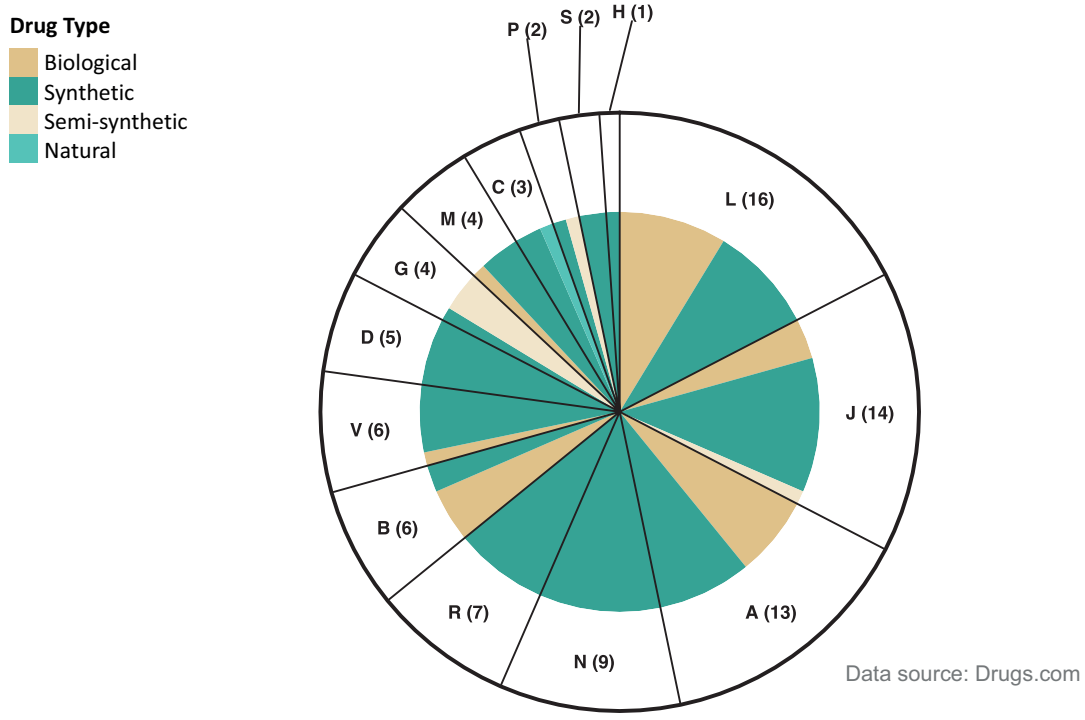


Figure 3 – FDA Approvals of Original Drugs in 2014.
Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic, or of natural origin.

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Scientific and Practical Journal
PHARMACY & PHARMACOLOGY
(ФАРМАЦИЯ И ФАРМАКОЛОГИЯ)

A	Insulin glargine Bile acid Deoxycholic acid Insulin degludec and insulin aspart Insulin degludec Asfotase alfa Sebelipase alfa Insulin glargine Empagliflozin and linagliptin Eluxadoline Empagliflozin and metformin Rolapitant Glycopyrrolate
B	Coagulation factor IX (recombinant) Fibrin sealant Antihemophilic factor (recombinant) Coagulation factor X (human) Antihemophilic factor (recombinant), pegylated Von Willebrand factor (recombinant) Edoxaban Ferric pyrophosphate citrate Cangrelor
C	Alirocumab Evolocumab Amlodipine besylate and perindopril arginine Ivabradine Sacubitril and valsartan Selexipag
D	Adapalene and benzoyl peroxide Betamethasone dipropionate and calcipotriene
G	Levonorgestrel Flibanserin
H	Parathyroid hormone
J	Meningococcal vaccine serogroup B Anthrax immune globulin Diphtheria and tetanus toxoids and acellular pertussis and inactivated poliovirus vaccine, DTaP-IPV Vaccine Influenza vaccine, adjuvanted Atazanavir and cobicistat Cobicistat and darunavir Lamivudine and raltegravir Avibactam and ceftazidime Isavuconazonium Ombitasvir, paritaprevir, and ritonavir Daclatasvir Cobicistat, elvitegravir, emtricitabine, and tenofovir alafenamide Ciprofloxacin
L	Secukinumab Filgrastim-sndz Dinutuximab Talimogene Laherparepvec Melolizumab Daratumumab Necitumumab Elotuzumab Tacrolimus ТрабектеTrabectedиндин Docetaxel Palbociclib Lenvatinib Panobinostat Glatiramer Acetate Sonidegib Tipiracil hydrochloride and trifluridine Irinotecan liposomal Cobimetinib Osimertinib Ixazomib Bendamustine hydrochloride Alectinib
M	Meloxicam Lesinurad
N	Morphine sulfate Carbidopa and levodopa Carbidopa and levodopa Paliperidone palmitate Brexpiprazole Levetiracetam Aspirin Cariprazine Arilpiprazole lauroxil Amphetamine Buprenorphine hydrochloride Methylphenidate hydrochloride
R	Albuterol sulfate Chlorpheniramine polistirex and codeine polistirex Olodaterol and tiotropium Chlorpheniramine and codeine Ivacaftor and lumacaftor Glycopyrrolate and indacaterol
S	Olopatadine HCl Dichlorphenamide
V	Idarucizumab Foscarnet Deferasirox Uridine triacetate Patiromer Naloxone Uridine triacetate Sugammadex

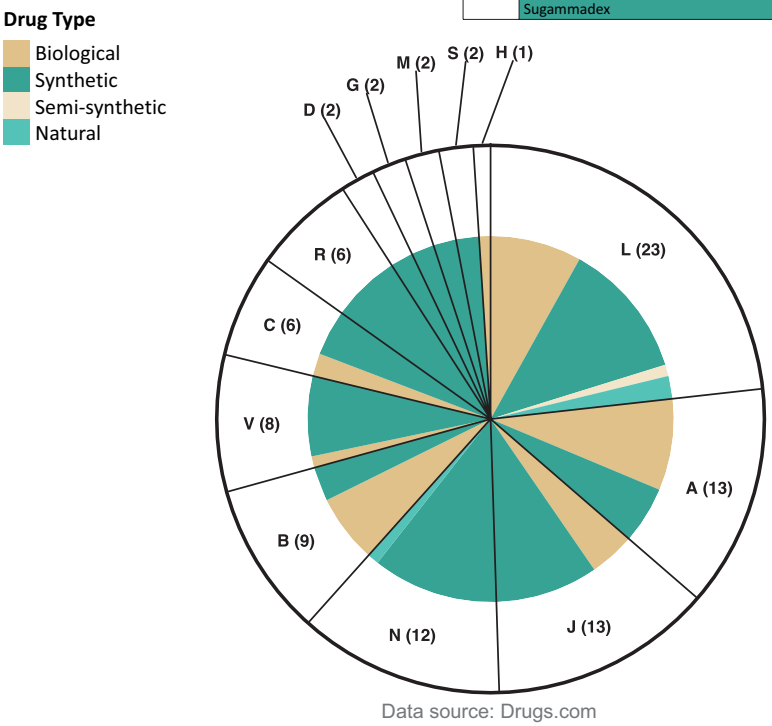

Figure 4 – FDA approvals of original drugs for 2015.

Note: the outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic or of natural origin.

ОБЗОР
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A	Lixisenatide
	Insulin degludec and liraglutide
	Obeticholic acid
	Calcifediol
	Dronabinol
	Granisetron
	Phentermine hydrochloride
	Aspirin and omeprazole
	Insulin glargine and lixisenatide
B	Coagulation factor IX (recombinant), albumin fusion protein
	Antihemophilic factor (recombinant)
	Defibrotide
	Antihemophilic factor (recombinant) single chain
C	Nebivolol and valsartan
	Nitroglycerin
	Lisinopril
D	Betamethasone dipropionate
	Crisaborole
G	Levonorgestrel
	Prasterone
J	Obiltoxaximab
	Influenza vaccine, inactivated
	Influenza vaccine, inactivated
	Cholera vaccine, live, oral
	Influenza vaccine, inactivated
	Human immunoglobulin
	Bezlotoxumab
	Elbasvir and Grazoprevir
	Emtricitabine, Rilpivirine and Tenofovir Alafenamide
	Emtricitabine, Rilpivirine and Tenofovir Alafenamide
	Sofosbuvir and Velpatasvir
	Dasabuvir, Ombitasvir, Paritaprevir and Ritonavir
	Tenofovir Alafenamide

L	Ixekizumab
	Infliximab-dyyb
	Atezolizumab
	Daclizumab
	Etanercept
	Adalimumab-atto
	Olaratumab
	Tofacitinib
	Melphalan
	Venetoclax
	Cabozantinib
	Aminolevulinic acid
	Rucaparib
N	Eteplirsen
	Nusinersen
	Amphetamine
	Sumatriptan
	Sumatriptan
	Brivaracetam
	Oxycodone
	Pimavanserin
	Buprenorphine
	Naltrexone and oxycodone
	Carbamazepine
P	Mebendazole
R	Reslizumab
	Ephedrine sulfate
	Acetylcysteine
	Formoterol fumarate and glycopyrrolate
	Fluticasone furoate
S	Bromfenac
	Ciprofloxacin and fluocinolone acetonide
	Oxymetazoline hydrochloride and tetracaine hydrochloride
	Lifitegrast
V	Fluciclovine F18
	Gallium 68

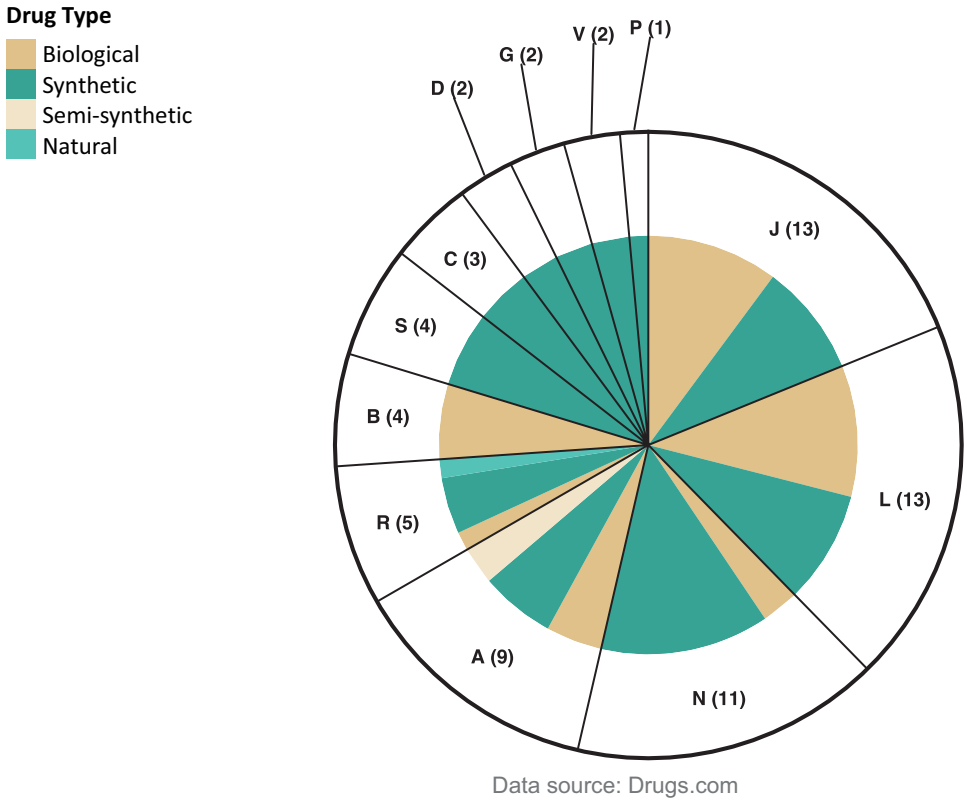

Figure 5 – FDA approvals of original drugs for 2016.
Note: the outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic or of natural origin.

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Scientific and Practical Journal
PHARMACY & PHARMACOLOGY
(ФАРМАЦИЯ И ФАРМАКОЛОГИЯ)

A	Cerliponase alfa Insulin aspart Exenatide Vestronidase alfa Semaglutide Insulin lispro Plecanatide Dapagliflozin and saxagliptin Telotristat ethyl Naldemedine Ascorbic acid Alrepitant Sodium picosulfate, magnesium oxide and anhydrous citric acid Glycopyrrolate Ertugliflozin Ertugliflozin and sitagliptin Ertugliflozin and metformin hydrochloride
B	Coagulation factor IX (recombinant), glycopegylated C1 esterase inhibitor (human) Emicizumab-kxwh Betrixaban
C	Angiotensin II Adrenaline Spironolactone Valsartan
D	Dupilumab Triamcinolone Acetonide Clobetasol Propionate Mometasone Furoate Ozenoxacin Hydrogen peroxide
H	Deflazacort Desmopressin Acetate Abaloparatide
J	Rabies Immunoglobulin Recombinant zoster vaccine Hepatitis B vaccine Delafloxacin Sofosbuvir, velpatasvir and voxilaprevir Glecaprevir and pibrentasvir Meropenem and vaborbactam Letermovir Dolutegravir and rilpivirine
L	Ixekizumab Infliximab-dyyb Atezolizumab Daclizumab Etanercept Adalimumab-atto Olaratumab Tofacitinib Melphalan Venetoclax Cabozantinib Aminolevulinic acid Acid Rucaparib
N	Eteplirsen Nusinersen Amphetamine Sumatriptan Sumatriptan Brivaracetam Oxycodone Pimavanserin Buprenorphine Naltrexone and oxycodone Carbamazepine
P	Mebendazole
R	Reslizumab Ephedrine sulfate Acetylcysteine Formoterol fumarate and glycopyrrolate Fluticasone furoate
S	Bromfenac Ciprofloxacin and fluocinolone acetonide Oxymetazoline hydrochloride and tetracaine hydrochloride Lifitegrast
V	Fluciclovine F18 Gallium 68

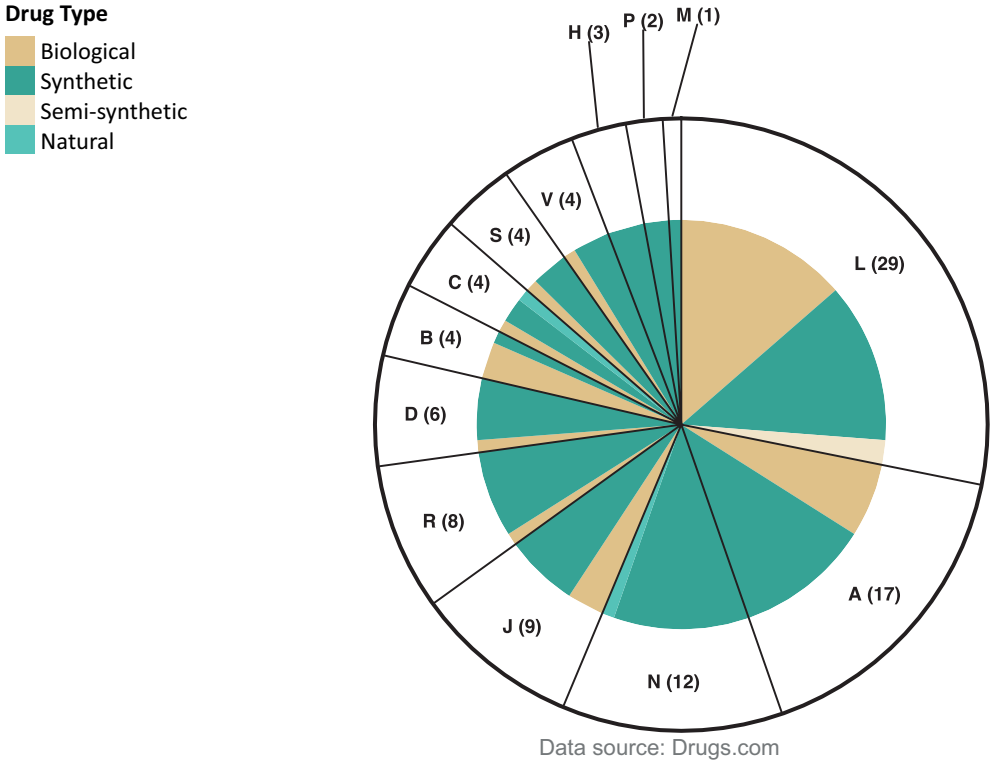
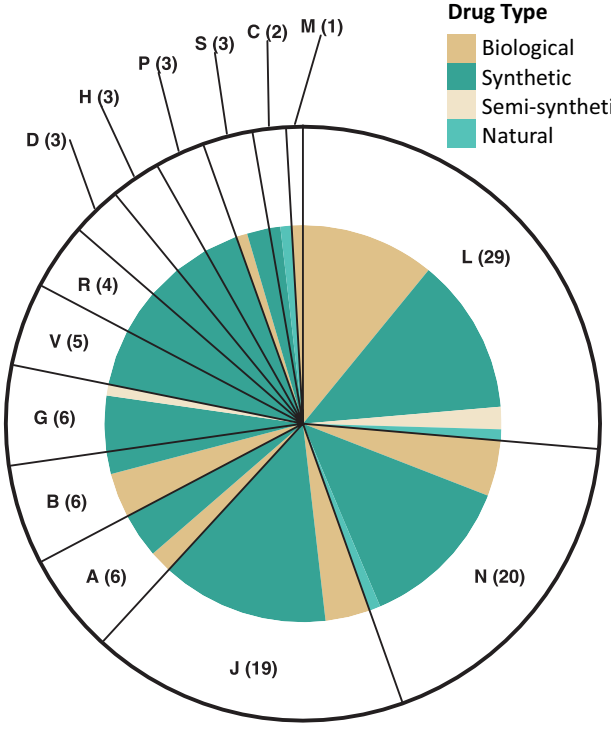


Figure 6 – FDA approvals of original drugs for 2017.

Note: the outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic or of natural origin.

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

A	Pegvaliaza-pqpz
	Elapegademase-dmde
	Fosnetupitant and palonosetron
	Polyethylene glycol 3350 with electrolytes
	Migalastat
	Prucalopride
B	Blood clotting factor Xa
	Epoetin alpha-epbx
	Lanadelumab-fli
	Antihemophilic factor
	Avatrombopag
	Lusutrombopag
C	Epinephrine
	Amlodipine and celecoxib
D	Tretinoin
	Fluocinolone acetonide
	Halobetasol propionate
G	Testosterone enanthate
	Ethinylestradiol/levonorgestrel and ferrous bisglycinate
	Estradiol
	Elagolix
	Ethinylestradiol and segesterone acetate
	Estradiol and progesterone
H	Dexamethasone
	Desmopressin Acetate
	Dexamethasone
J	Vancomycin hydrochloride
	Ibalizumab-uiyk
	Rifamycin
	Hexavallent vaccine
	Efavirenz, lamivudine and tenofovir disoproxil fumarate
	Bictegravir, emtricitabine and tenofovir alafenamide
	Ламивудин и тенофовира дизопроксил фумарат
	Lamivudine and tenofovir disoproxil fumarate
	Plazomicin
	Tecovirimat
	Cobicistat, darunavir, emtricitabine and tenofvir alafenamide
	Eravacycline
	Doravirine
	Doravirine, lamivudine and tenofovir disoproxil fumarate
	Liposomal amikacin
	Sarecycline
	Omadacycline
	Baloxavir Marboxil
	Itraconazole
L	Tildrakizumab-asmn
	Pegfilgrastim
	Filgrastim-aafi
	Mogamulizumab-kpkc
	Cemiplimab rwlc
	Adalimumab-adaz
	Pegfilgrastim-cbqv
	Emapalumab-lsge
	Rituximab-abs
	Trastuzumab-pkrb
	Calaspargase Pegol-mknl
	Ravulizumab-cwvz
	Cyclosporine
	Moxetumomab Pasudotox-tdfk
	Tagraxofusl-erzs
	Apalutamide
	Fostamatinib
	Abiraterone Acetate
	Baricitinib
	Encorafenib
	Binimetinib
	Ivosidenib
	Duvelisib
	Dacomitinib
	Talazoparib
	Lorlatinib
	Glasdegib
	Larotrectinib
	Gilteritinib
M	Burosumab-tza
N	Erenumab-aooe
	Patisiran
	Fremanezumab-vfrm
	Galcanezumab
	Inotersen
	Cannabidiol
	Amantadine hydrochloride
	Acetaminophen and benzhydrocodone hydrochloride
	Lidocaine
	Lofexidine hydrochloride
	Risperidone
	Methylphenidate hydrochloride
	Stiripentol
	Riluzole
	Buprenorphine and naloxone
	Clobazam
	Sufentanil
	Amifampridine Phosphate
	Levetiracetam
	Levodopa
P	Moxidectin
	Tafenoquine
	Tafenoquine
R	Ivacaftor / Tezacaftor and Ivacaftor
	Glycopyrronium
	Revefenacin
	Albuterol sulfate
S	Cenegermin-bkbj
	Loepernol etabonate
	Latanoprost
V	Lutetium Lu 177 dotatate
	Tolvaptan
	Sodium zirconium cyclosilicate
	Iobenguane I 131



Data source: Drugs.com

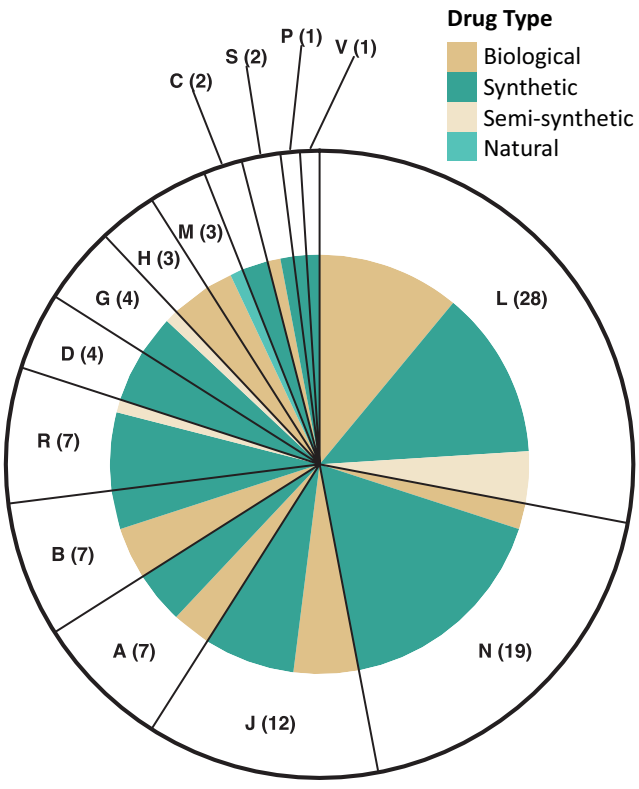
Figure 7 – FDA approvals of original drugs in 2018.

Note: the outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic or natural origin.

ISSN 2307-9266 e-ISSN 2413-2241

Scientific and Practical Journal
PHARMACY & PHARMACOLOGY
(ФАРМАЦИЯ И ФАРМАКОЛОГИЯ)

A	Human insulin in sodium chloride solution Semaglutide Givosiran Cellulose and citric acid Dapagliflozin, metformin hydrochloride and saxagliptin Tenalanor Amoxicillin, omeprazole and rifabutin
B	Caplacizumab Turoctocog Alfa Pegol Luspatercept-aamt Caplacizumab Iron maltol Voxelotor Cysteine hydrochloride
C	Amlodipine benzoate Левамлодипина малеат
D	Levamlodipine propionate and tazarotene Trifarotene Amafepanotide Tazarotene
G	Testosterone undecanoate Drospirenone Bremelanotide Ethinylestradiol and Etonogestrel
H	Glucagon Glucagon Teriparatide
J	Immunoglobulin Quadrivalent dengue fever vaccine Subcutaneous immunoglobulin Smallpox vaccine Ebola vaccine Acyclovir Dolutegravir and lamivudine Imipenem, cilastatin and relebactam Pretomanid Lefamulin Minocycline Cefiderocol
L	Trastuzumab Trastuzumab Risankizumab-rzaa Etanercept Trastuzumab-anns Bevacizumab Rituximab Adalimumab Pegfilgrastim-bmez Adalimumab Infliximab Trastuzumab and hyaluronidase Polatuzumab Vedotin Enfortumab Vedotin Fam-Trastuzumab Deruxtecan Silonimod Cladribine Erdafitinib Alpelisib Selinexor Darolutamide Pexidartinib Энтректиниб Fedratinib Uladacitinib Diroximel fumarate Zanubrutinib Methotrexate
M	Prabotulinumtoxin Romosozumab Colchicine
N	Onasemnogene Abeparvovec Golodirsen Sumatriptan Methylphenidate hydrochloride Esketamine Brexanolone Solriamfetol Tafamidis meglumine Amifampridine Midazolam Pitolisant Istradefylline Lasmiditan Asenapine Cenobamate Riluzole Lumateperone Lemborexant Ubrogepant
P	Triclabendazole
R	Budesonide Fluticasone Propionate and salmeterol Aclidinium bromide and formoterol fumarate Fluticasone propionate and sameterol Cetirizine hydrochloride Elexacaftor / Tezacaftor / Ivacaftor and Ivacaftor Phenylephrine hydrochloride
S	Brolucizumab Netarsudil and Latanoprost
V	Tiopronin



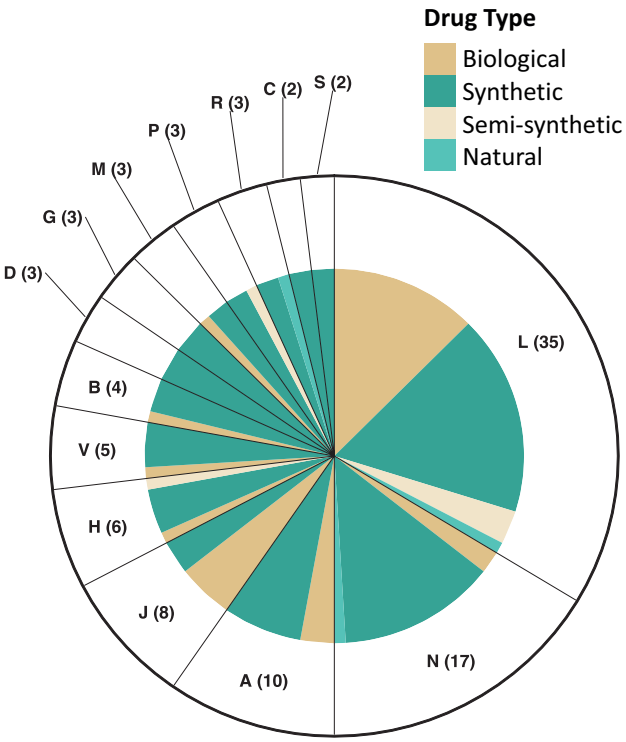
Data source: Drugs.com

Figure 8 – FDA approvals of original drugs in 2019.

Note: the outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic or natural origin.

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

A	Insulin glargine Insulin lispro Lumasiran Empagliflozin, linagliptin and metformin hydrochloride Lactitol Lactic acid, citric acid and sodium bitartrate Metoclopramide Triheptanoin Cysteamine hydrochloride Sodium sulfate, magnesium sulfate and potassium chloride
B	Blood coagulation factor VIIa (recombinant)-jncw Ferric derisomaltose Mannitol Berotralstat
C	Bempedoic acid Bempedoic acid and ezetimibe
D	alcipotriene and betamethasone dipropionate Clascoterone Tirbanibulin
G	Ethinylestradiol and levonorgestrel Elagolix/estradiol/norethindrone acetate and Elagolix Vibegron
H	Somalacitan Hydrocortisone Osilodrostat Octreotide Setmelanotide Levothyroxine sodium
J	Monovalent influenza A vaccine Influenza vaccine, adjuvanted Meningococcal (groups A, C, Y, W) conjugate vaccine Atoltivimab, Maftivimab and Odesevimab Ansuvimab Minocycline Fostemsavir Remdesivir
L	Teprotumumab Isatuximab Pegfilgrastim Inebilizumab Adalilumab Brexucabtagene Autoleucel Tafasitamab Satralizumab Ofatumumab Naxitamab Margetuximab Rituximab Mitomycin Sacituzumab Govitecan Daratumumab and Hyaluronidase Balantamab mafodotin Avapritinib Tazemetostat Pemetrexed Ozanimod Selumetinib Pemigatinib Tucatinib Monomethyl fumarate Leuprolide acetate Capmatinib Selpercatinib Ripretinib Lurbinectedin Decitabine and cedazuridine Azacitidine Pralsetinib Lonafarnib Relugolix Pertuzumab, trastuzumab and hyaluronidase-zzxf
M	Collagenase Clostridium Histolyticum-aaes Meloxicam Celecoxib
N	Eptinezumab Viltoarsen Cocaine hydrochloride Diazepam Amisulpride Rimegepant Ibuprofen and acetaminophen Opicapone Apomorphine hydrochloride Fenfluramine Remimazolam Calcium, magnesium, potassium and sodium oxybates Oliceridine Risdiplam Bupivacaine hydrochloride Tramadol hydrochloride Fosphenytoin sodium
P	Artesunate Abametapir Nifurtimox
R	Ephedrine sulfate Oxymetazoline hydrochloride Budesonide/glycopyrrolate/formoterol fumarate
S	Bimatoprost Loteprednol etabonate
V	Peanut allergen extract Fluorestradiol F18 Flortaucipir F18 Medi 64 dotatate Gallium 68 PSMA-11



Data source: Drugs.com

Figure 9 – FDA approvals of original drugs in 2020.
Note: the outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic or natural origin.

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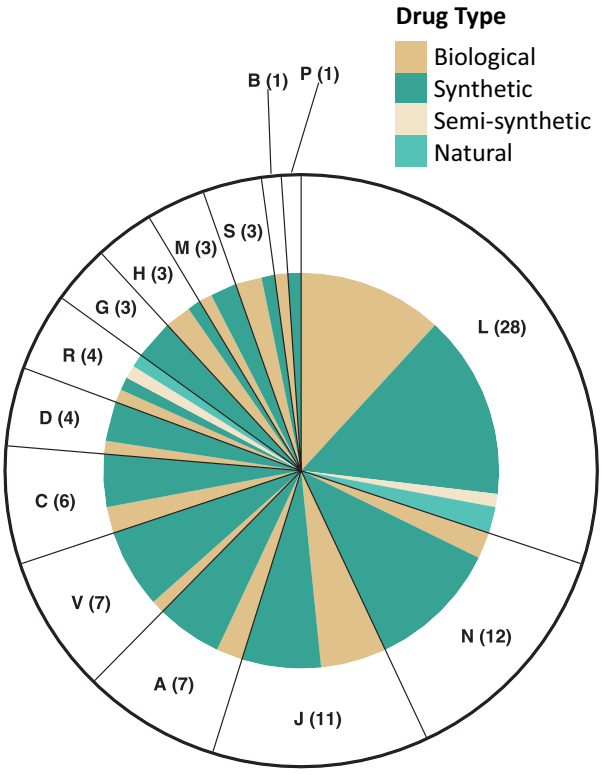
Scientific and Practical Journal
PHARMACY & PHARMACOLOGY
(ФАРМАЦИЯ И ФАРМАКОЛОГИЯ)

A	Semaglutide Avalglucosidase alpha Fosdenopterin Sotagliflozin Odevixibat Maralixibat Glycopyrrolate
B	Human plasminogen
C	Evinacumab Inclisiran Vericiguat Ezetimibe and rosuvastatin Torsemide Finerenone
D	Tralokinumab Tretinoin and benzoyl peroxide Triamcinolone acetonide Clindamycin phosphate
G	Drospirenone and estetrol Relugolix, estradiol and norethindrone acetate Finasteride and tadalafil
H	Dasiglucagon Lonapegsomatropin Levoketoconazole
J	Pneumococcal 20-valent conjugate vaccine Pneumococcal 15-valent conjugate vaccine Tick-borne encephalitis Vaccine against encephalitis COVID-19 vaccine Hepatitis B vaccine Cabotegravir and rilpivirine Oritavancin Ibrexafungerp Brincidofovir Maribavir Cabotegravir
L	Lisocabtagene Maraleucel Idecabtagen Wikileucel Dostarlimab Pegcetacoplan Amivantamab Asparaginase Erwinia Chrysanthemi (recombinant) Anifrolumab Tisotumab Ropeginterferon alfa-2b Adalimumab Efgartigimod Cyclosporine Sirolimus Loncastuximab Tesirine Voclosporin Umbralisib Trilaciclib Melphalan Flufenamide Tivazanib Ponesimod Leuprolide Mesylate Infigratinib Belumosudil Belzutifan Mobocertinib Ruxolitinib Avacopan Aciminib
M	Vosoritide Celecoxib and tramadol hydrochloride Baclofen
N	Casimersen Aducanumab Bupivacaine Dexmethylphenidate and serdexmethylphenidate Viloxazine hydrochloride Bupivacaine and meloxicam Olanzapine and samidorphan Paliperidone palmitate Dihydroergotamine mesylate Atogepant Varenicline Topiramate
P	Fexinidazole
R	Tezepelumab Ephedrine hydrochloride Budesonide Azelastine
S	Ranibizumab Ranibizumab Pilocarpine hydrochloride
V	Allogeneic processed thymus tissue Naloxone hydrochloride Piflufolastat F18 Difelikefalin Naloxone hydrochloride Paflocyanine Gallium 68 Gozetotide



Data source: Drugs.com

Figure 10 – 2021 FDA Original Drug Approvals.

Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic, or of natural origin.

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

A	Tirzepatide Olipudase alfa Fecal microbiota, live Триентин тетрагидрохлорид Amoxicillin, clarithromycin, and vonoprazan Omeprazole and sodium bicarbonate Aprepitant Sodium phenylbutyrate and taurursodiol Sodium phenylbutyrate
B	Betibeglogene autotemcel Etranacogene dezaparvovec Mitapivat
C	Amlodipine besylate Mavacamten Furosemide
D	Anacaulase Benzoyl peroxide Tapinarof
G	Testosterone Testosterone undecanoate
H	Terlipressin
J	COVID-19 vaccine Measles, mumps, and rubella vaccine, live Oteseconazole Lenacapavir
L	Tebentafusp Sumimlimab Filgrastim Ciltacabtagene autoleucel Nivolumab and relatlimab Bevacizumab Pegfilgrastim Pegfilgrastim Spesolimab Eflapegrastim Bevacizumab Tremelimumab Teclistamab Teplizumab Adalimumab Nadroparagene firadenovec Mosunetuzumab Ublituximab Sirolimus Mirvetuximab soravtansine Abrocitinib Pacritinib Alpelisib Deucravacitinib Futibatinib Olutasidenib Adagrasib
M	Daxibotulinumtoxin A Baclofen
N	Vutrisiran Elivaldogene autotemcel Daridorexant Donepezil Ganaxolone Dextroamphetamine Dexmedetomidine Edaravonен Vigabatrin Zonisamide Dextromethorphan and bupropion Chloroprocaine hydrochloride Phenobarbital sodium
R	Mometasone furoate and olopatadine hydrochloride Mometasone furoate monohydrate Roflumilast
S	Faricimab Ranibizumab Omidenepag isopropyl Latanoprost
V	Technetium Tc 99m succimer Gallium Ga 68 gozetotide Lutetium Lu 177 vipivotide tetraxetan Indigotindisulfonate sodium Sodium thiosulfate Gadopiclenol Xenon Xe 129 hyperpolarized

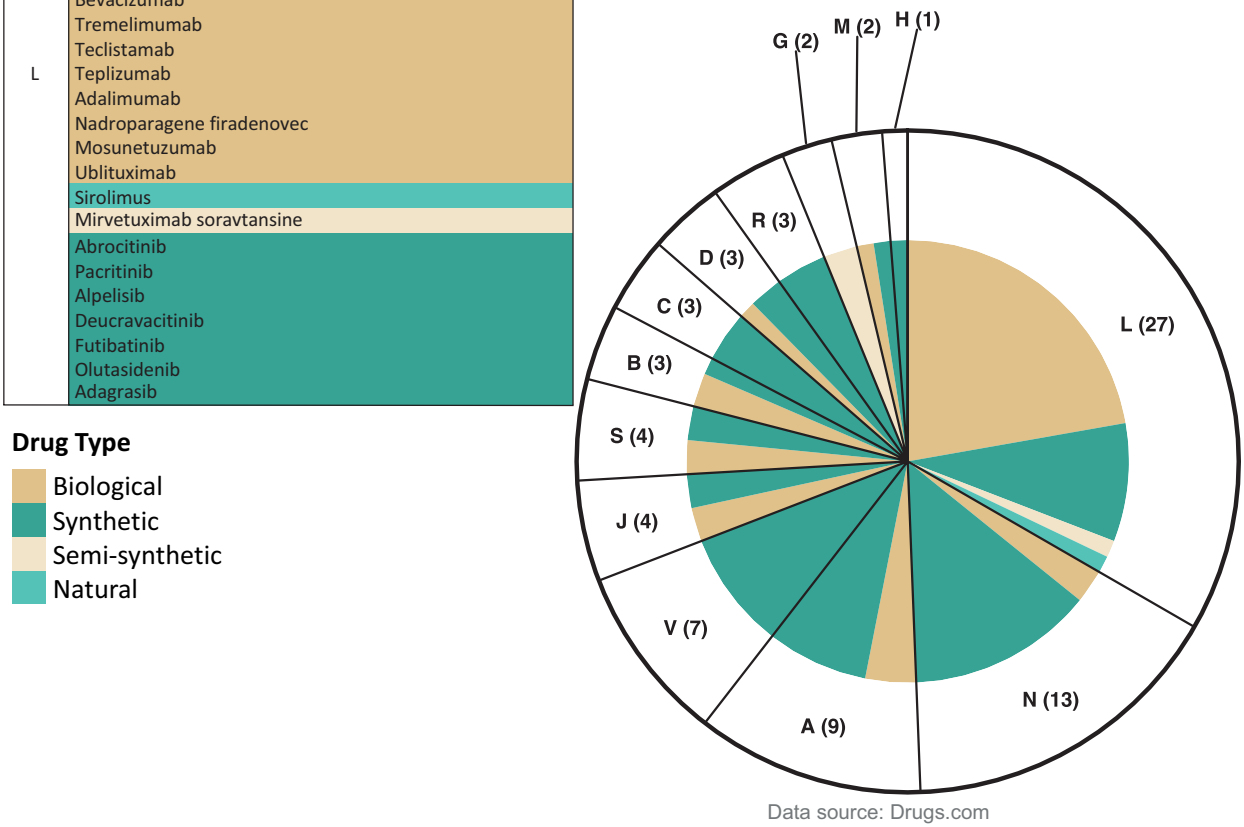


Figure 11 – 2022 FDA Original Drug Approvals.
Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic, or of natural origin.

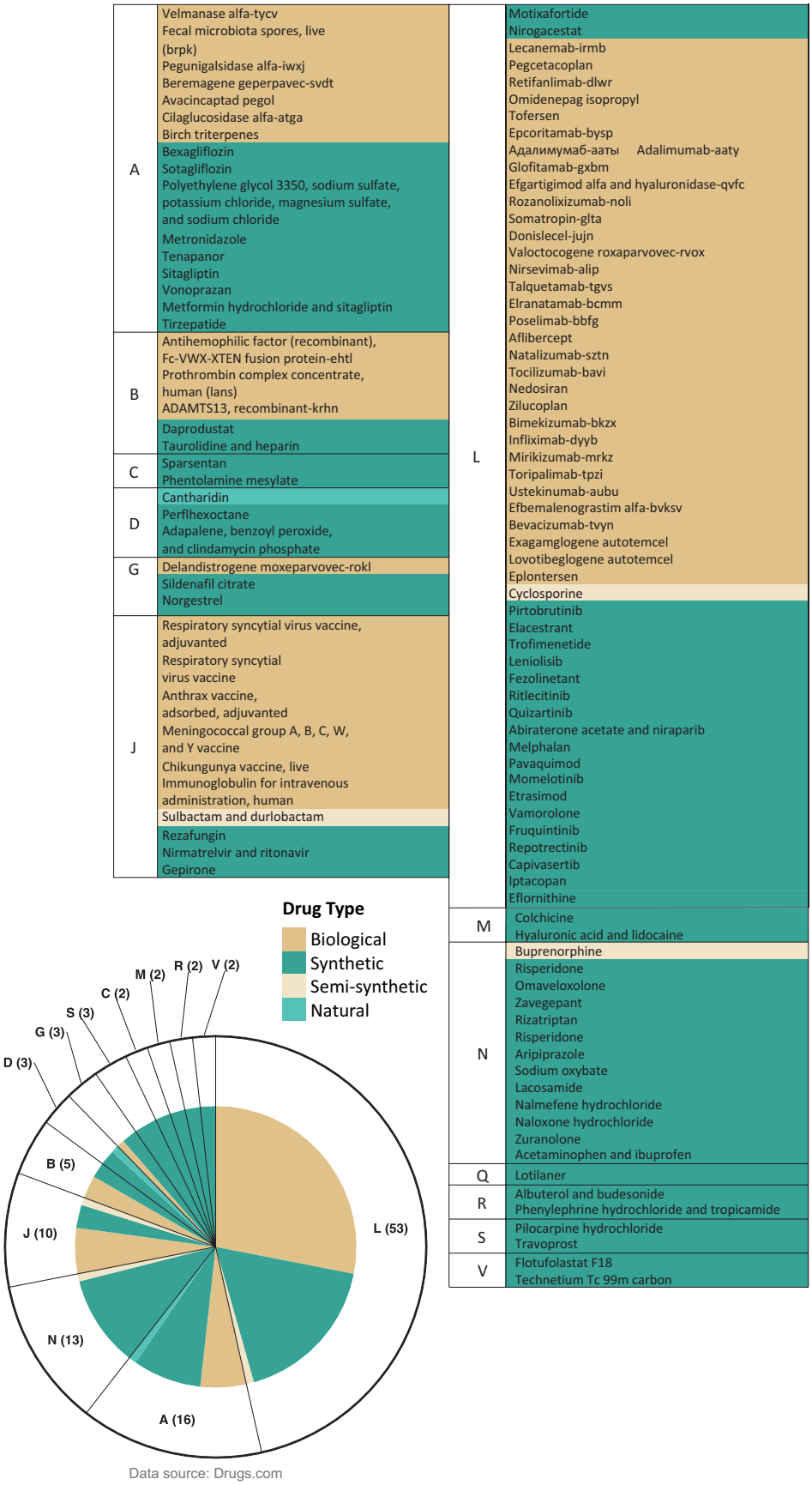


Figure 12 – 2023 FDA Original Drug Approvals.

Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological, synthetic, semi-synthetic, or of natural origin.

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

A	Seladelpar
	Elafibranor
	Resmetirom
B	Concizumab-mtci
	Marstacimab-hncq
	Vadadustat
C	Olezarsen
	Sotatercept-CSRK
	Landiolol
	Acoramidis
	Aprocitentan
D	Lebrikizumab-lbkz
	Nemolizumab-ilto
	Deucravacitinib
	Sofpironium
	Berdazimer
H	Palopegteriparatide
	Crinecerfont
J	Ceftobiprole medocaril sodium
	Cefepime and enmetazobactam
	Sulopenem and etzadroxil and probenecid
L	Danicopan
	Cosibelimab-ipdl
	Zenocutuzumab-zbko
	Zanidatamab-zfri
	Zolbetuximab-clzb
	Axatilimab-csfr
	Crovalimab-akkz
	Tarlatamab-dlle
	Nogapendekin alfa inbakicept-pmln
	Tislelizumab-jsgr
	Ensartinib
	Revumenib
	Ivosidenib
	Lazertinib
	Vorasidenib
	Imetelstat
	Mavorixafor
	Tovorafenib
M	LetibotulinumtoxinA-wlbg
N	Lecanemab-irmb
	Donanemab-aduc
	Xanomeline and trospium chloride
	Levacetylleucine
	Arimoclomol
	Givinostat
R	Vanacaftor, tezacaftor and deutivacaftor
	Ensifentrine
V	Iomeprol
	Flurpiridaz
	Pegulicianine

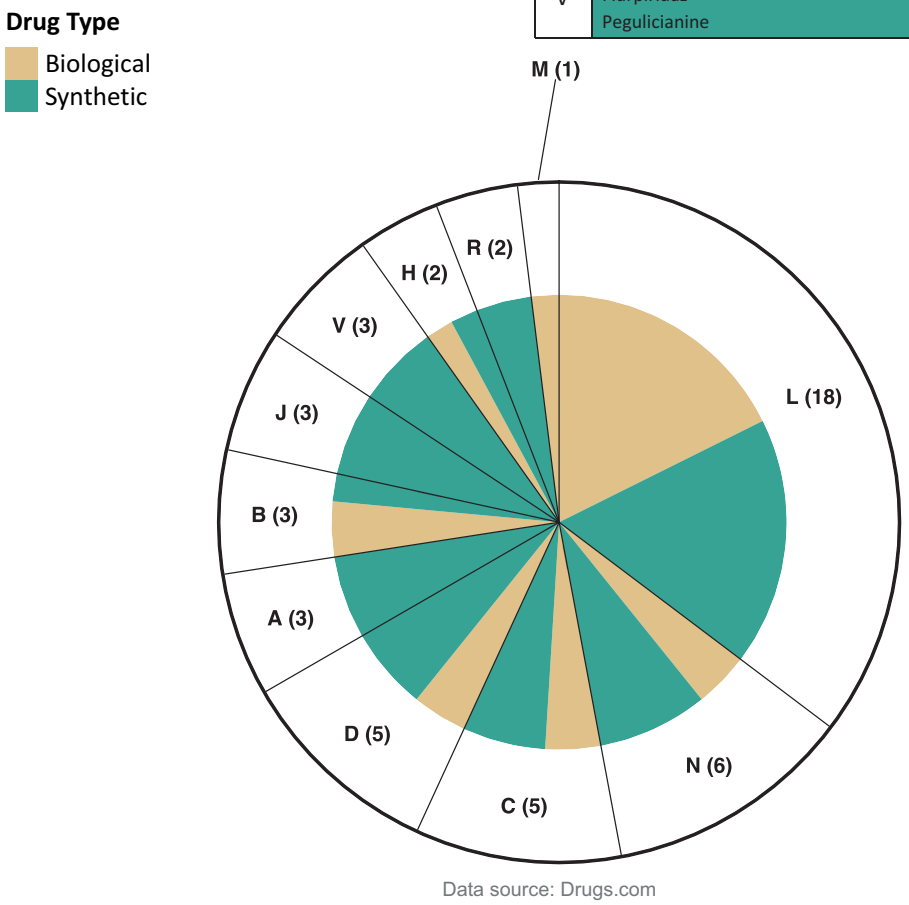


Figure 13 – 2024 FDA Original Drug Approvals.
Note: The outer ring corresponds to the proportions of drugs according to the first letter of their ATC class; the segments of the inner ring correspond to the proportion of drug types — biological or synthetic.

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Scientific and Practical Journal
PHARMACY & PHARMACOLOGY
(ФАРМАЦИЯ И ФАРМАКОЛОГИЯ)

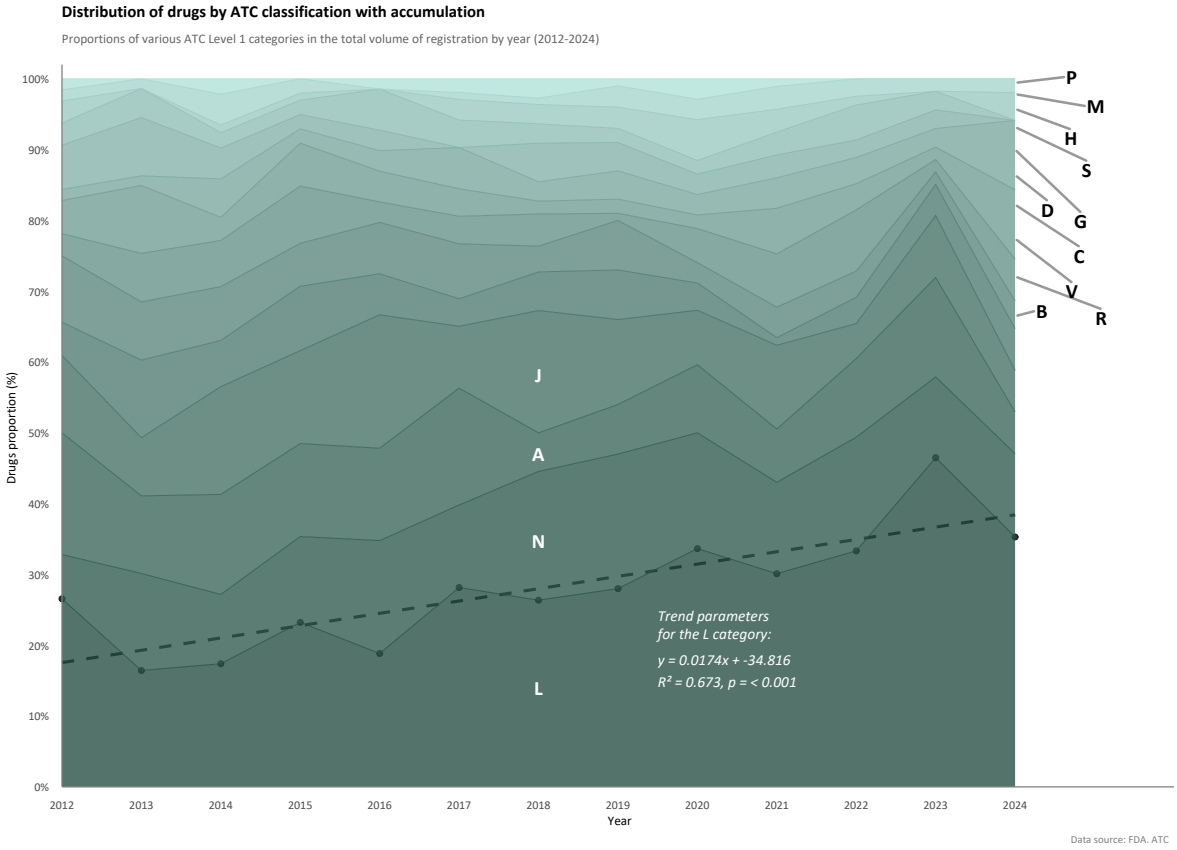

Figure 14 – Drugs approved by the FDA according to the anatomical and therapeutic classification in the period from 2013 to 2024.

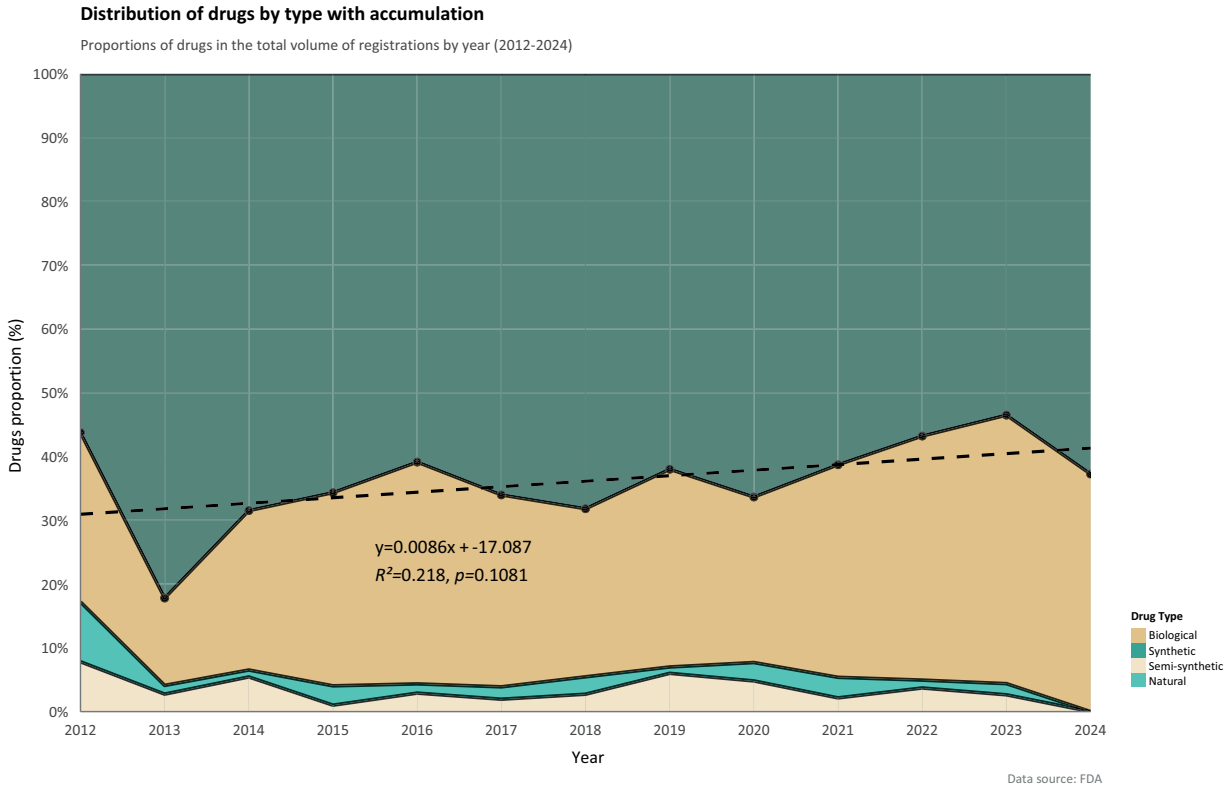

Figure 15 – Distribution of various types of production of original drugs during 2012–2024.

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

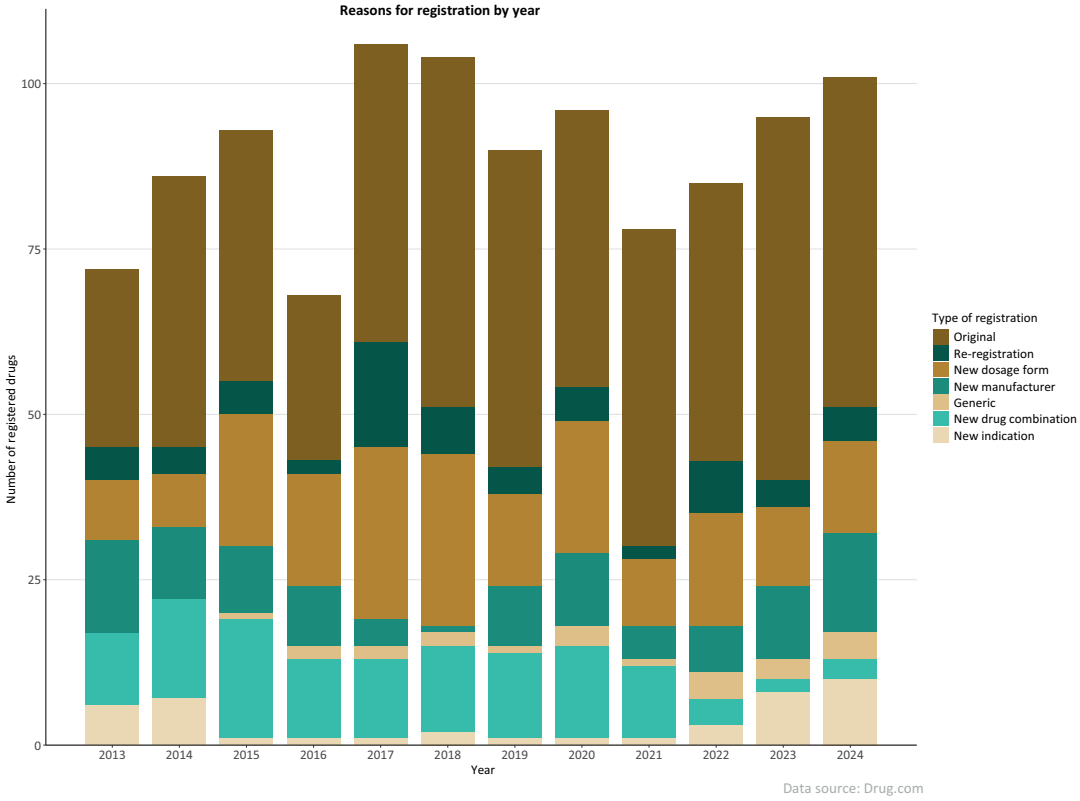

Figure 16 – Cumulative chart of the number of reasons for registration by year.
Note: the data is presented as the number of drugs registered in the specified year.

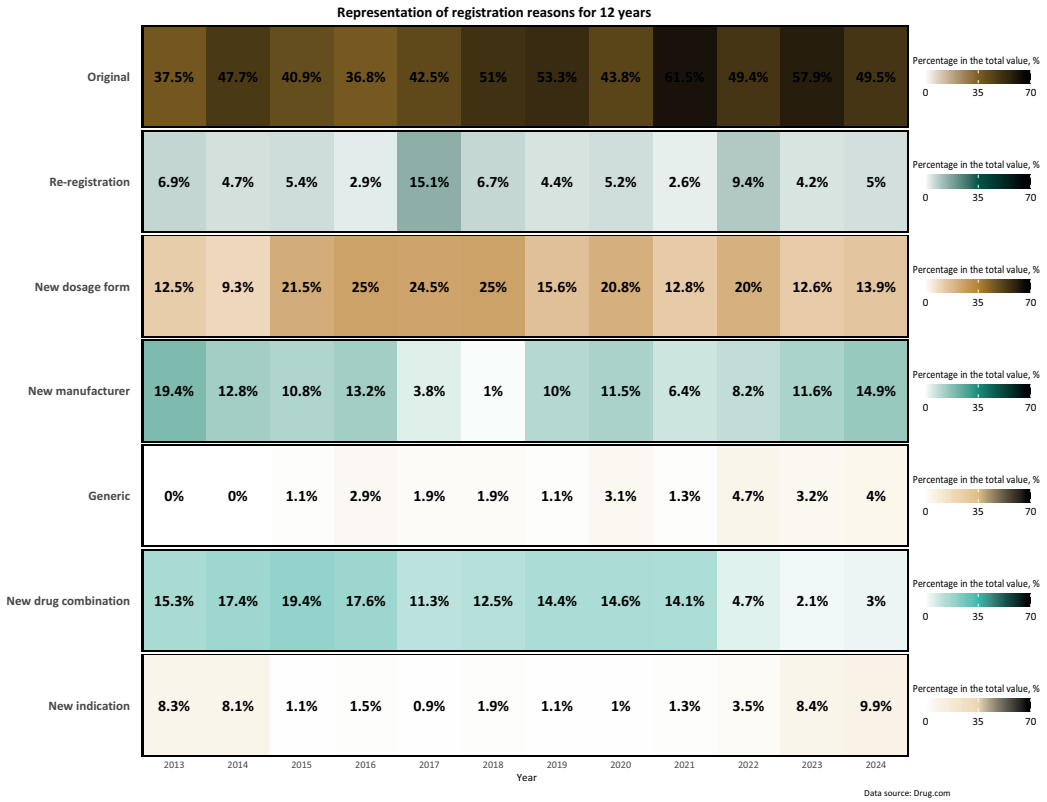

Figure 17 – Representation of drugs registered for various reasons in the registration structure of the designated year (registration shares by year).
Note: Please note that the gradient temperature is limited to 70%, as none of the registration reasons exceeded this threshold.

Aflibercept (Eylea HD®)[313] is a recombinant hybrid protein consisting of the extracellular domains of human vascular endothelial growth factor (VEGF) receptors 1 and 2, linked to the Fc fragment of human IgG1. Eylea HD® is approved for the treatment of wet macular degeneration (2011), diabetic macular edema (since 2014), diabetic retinopathy at all stages (since 2019) and retinopathy of prematurity since 2023. In wet macular degeneration, abnormal blood vessels grow in the choriocapillaries — a layer of capillaries under the retina, which leads to leakage of blood and protein under the macula. Aflibercept binds to circulating VEGF and acts as its trap and inhibits the activity of its subtypes (VEGF-A and VEGF-B), as well as placental growth factor, suppressing the growth of new blood vessels in the choriocapillaries or tumor, respectively (tumor depletion) [79].

2024

In 2024, 106 drugs were approved. 50 original molecules were approved, including 15 new original anticancer drugs. In 2024, a record number (10) of drugs of known medicines approved for a new indication was identified. 15 drugs that changed manufacturers, 4 generics, and 3 new combinations were approved. It is important to note that 2024 is the only year when no semi-synthetic or natural molecules were registered among the original molecules (Fig. 13). Among the 50 original molecules, almost half were “first-in-class” drugs. Most of the new products were small molecules (about 60%), but the proportion of biologics increased significantly (about 34%), mainly monoclonal antibodies with antitumor and anti-inflammatory effects.

Among the registered drugs are bispecific antibodies, new tyrosine kinase inhibitors, and innovative oligonucleotide drugs for rare (orphan) diseases. For example, zenocutuzumab (Bizengri®) is a bispecific antibody to HER2 / HER3 for the treatment of non-small cell lung cancer[314], and olezarsen (Tryngolza®) is an oligonucleotide for the treatment of familial chylomicronemia[315].

Significant attention is paid to the treatment of malignant tumors: new antibodies have appeared, such as cosibelimab (Unloxcyt®) for the treatment of squamous cell skin cancer when surgery or radiation therapy is not possible. Among the drugs for orphan diseases, protein stabilizers for amyloid cardiomyopathy and drugs for the correction of rare lipid metabolism disorders have been registered.

Zenocutuzumab (Bizengri®) provides simultaneous blockade of two tumor growth signaling pathways. This combination reduces the likelihood of drug resistance and enhances the antitumor effect. Zenocutuzumab is especially valuable for patients with mutations that respond poorly to existing HER2-targeted agents[316].

Cosibelimab (Unloxcyt®) blocks the interaction of PD-L1 with PD-1, removing the inhibition of antitumor immunity. It is intended for patients who do not respond to standard treatments and is an immunotherapy option with a high potential for life extension[317].

Ensartinib (Ensacove®) is a new generation drug capable of overcoming resistance to previously approved ALK inhibitors. It is effective against tumors with mutations that reduce sensitivity to crizotinib and other analogs[318].

Olezarsen (Tryngolza®) reduces the level of apolipoprotein C-III, which leads to a marked decrease in triglycerides. This is the first drug of its kind with a proven ability to control a pathology for which there were previously almost no effective means[319].

Zanidatamab (Ziihera®) has demonstrated the ability to block pathological HER2 signals in non-oncological tissues, slowing organ damage and improving their function. This is one of the first examples of the transfer of antitumor mAb technologies for the treatment of non-cancerous diseases[320].

Therapy based on mAbs interacting with receptors, as well as immunotherapy based on newly discovered mechanisms of antitumor immunity, occupies a separate part in the structure of registered original drugs. The search for new rational combinations of antibiotics remains relevant.

[313] Drugs.com. Eylea HD. Available from: https://www.drugs.com/eylea-hd.html
[314] Drugs.com. Bizengri. Available from: https://www.drugs.com/bizengri.html
[315] Drugs.com. Tryngolza. Available from: https://www.drugs.com/tryngolza.html
[316] Drugs.com. Bizengri. Available from: https://www.drugs.com/bizengri.html
[317] Drugs.com. Unloxcyt. Available from: https://www.drugs.com/unloxcyt.html
[318] Drugs.com. Ensacove. Available from: https://www.drugs.com/ensacove.html
[319] Drugs.com. Tryngolza. Available from: https://www.drugs.com/tryngolza.html
[320] Drugs.com. Ziihera. Available from: https://www.drugs.com/ziihera.html

ОБЗОР
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DISCUSSION

Structure according to the anatomical therapeutic chemical classification

Analyzing the presented data, several main and significant trends in FDA approvals can be noted. First of all, the proportion of original molecules and new combinations has remained stable over the past decades, but the proportion of biotechnological products has gradually increased, including due to the focus on small groups of patients with rare and orphan diseases [9]. It should also be noted that biotechnology startups are of greater interest to investors than those focused on synthetic chemistry methods due to certain specifics that determine the development strategy and advantages of such drugs [80, 81]. At the same time, the number of approved generic drugs in the United States seems minimal, while drugs in new dosage forms are more often approved, which, apparently, are designed to meet the needs of individual groups of patients.

The most extensive group of drugs in the ATC classification was anticancer drugs and immunomodulators, which is due to both progress in the treatment of oncological diseases and the belonging to this group of many drugs based on monoclonal antibodies intended for the treatment of an extensive list of pathologies, including systemic inflammatory and neurodegenerative diseases [82–84]. Examples of such drugs approved for the period 2012–2024 include ponatinib (Iclusig®) — a tyrosine kinase inhibitor intended for the treatment of chronic myeloid leukemia (CML) and acute leukemias with certain mutations[321]; daclizumab (Zinbryta®) — a monoclonal antibody to IL-2, intended for the treatment of multiple sclerosis, but also used in oncology[322]; elotuzumab (Empliciti®) — a monoclonal antibody for the treatment of multiple myeloma[323]; cobimetinib (Cotellic®) — a MEK inhibitor that is used in combination with vemurafenib to increase the effectiveness of melanoma treatment[324]; avelumab (Bavencio®) — a PD-L1 inhibitor approved for the treatment of bladder and kidney cancer[325]; tazemetostat (Tazverik®) — an EZH2 inhibitor approved for the treatment of soft tissue sarcoma[326]; venetoclax (Venclexta®) — an inhibitor of the BCL-2 protein, which activates apoptosis of cancer cells, which is used to treat chronic lymphocytic leukemia[327]; tralokinumab (Adbry®) — a monoclonal antibody that blocks IL-13, used to treat atopic dermatitis[328]; dostarlimab (Jemperli®) — a PD-1 inhibitor approved for the treatment of endometrial cancer[329]; teplizumab (Tzield®) — a monoclonal antibody used to slow the progression of type 1 diabetes[330]; a combination of three monoclonal antibodies that neutralizes the Ebola virus: atoltivimab, maftivimab, and odesivimab (Inmazeb®)[331] [20, 85, 86].

Interest in the development of drugs affecting the digestive tract and metabolism, and drugs for the treatment of diseases of the nervous system remains steadily high: many drugs that are the first in their class, that is, having a fundamentally new mechanism of action, have appeared in these areas. Among the drugs from this category that received FDA approval for the treatment of diabetes mellitus and obesity in 2012–2024, the following drugs should be highlighted: canagliflozin (Invokana®) — the first drug in the class of SGLT2 inhibitors[332], intended for the treatment of type 2 diabetes, and dapagliflozin (Farxiga®, also an SGLT2 inhibitor)[333], dulaglutide (Trulicity®)[334] and semaglutide (Ozempic®)[335] — GLP-1 analog drugs intended for the treatment of type 2 diabetes, which help control blood glucose levels and promote weight loss. A number of combinations of representatives of this class with other hypoglycemic agents: liraglutide and insulin degludec (Xultophy®)[336], as well as the dual incretin tirzepatide — an agonist of glucose-

[321] Drugs.com. Iclusig. Available from: https://www.drugs.com/iclusig.html
[322] Drugs.com. Zinbryta. Available from: https://www.drugs.com/zinbryta.html
323 Drugs.com. Empliciti. Available from: http://drugs.com/empliciti.html
[324] Drugs.com. Cotellic. Available from: https://www.drugs.com/cotellic.html
[325] Drugs.com. Bavencio. Available from: https://www.drugs.com/bavencio.html
[326] Drugs.com. Tazverik. Available from: https://www.drugs.com/tazverik.html
[327] Drugs.com. Venclexta. Available from: https://www.drugs.com/venclexta.html
[328] Drugs.com. Adbry. Available from: https://www.drugs.com/adbry.html
[329] Drugs.com. Jemperli. Available from: https://www.drugs.com/jemperli.html
[330] Drugs.com. Tzield. Available from: https://www.drugs.com/tzield.html
[331] Drugs.com. Inmazeb. Available from: https://www.drugs.com/cons/inmazeb.html
[332] Drugs.com. Invokana. Available from: https://www.drugs.com/invokana.html
[333] Drugs.com. Farxiga. Available from: https://www.drugs.com/farxiga.html
[334] Drugs.com. Trulicity. Available from: https://www.drugs.com/trulicity.html
[335] Drugs.com. Ozempic. Available from: https://www.drugs.com/ozempic.html
[336] Drugs.com. Xultophy. Available from: https://www.drugs.com/xultophy.html

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Scientific and Practical Journal
PHARMACY & PHARMACOLOGY
(ФАРМАЦИЯ И ФАРМАКОЛОГИЯ)

dependent insulinotropic polypeptide and GLP-1 receptors (Mounjaro® and Zepbound®)[337, 338], intended for the treatment of diabetes mellitus and obesity, respectively. For the treatment of neuropsychiatric disorders during the same period, among other drugs, dextromethorphan + quinidine (Nuedexta®) was approved for the treatment of pseudobulbar affect, which helps control sudden episodes of laughter or crying[339], brexpiprazole (Rexulti®) — an atypical antipsychotic that affects dopamine and serotonin receptors, approved for the treatment of schizophrenia and as an adjunct therapy for the treatment of depression[340]; cariprazine (Vraylar®) — an atypical antipsychotic that affects dopamine and serotonin receptors, approved for the treatment of schizophrenia and bipolar disorder[341]; erenumab (Aimovig®) — a monoclonal antibody for the prevention of migraine in adults, which blocks CGRP, reducing the frequency of migraine[342]; aducanumab (Aduhelm®)[343], lecanemab (Lecanemab®)[344] and donanemab (Donanemab®)[345] — monoclonal antibodies that target β-amyloid plaques in the brain and are intended for the treatment of Alzheimer's disease; cerliponase alfa (Brineura®) — a gene therapy drug for the treatment of a neurodegenerative disease associated with Batten disease[346]; imiglucerase (Cerezyme®) — an enzyme replacement therapy drug approved for the treatment of Gaucher disease[347].

Progress also continued in the field of antimicrobial drugs for systemic use, which include both antibacterial and antiviral drugs. It is important to note that the COVID-19 pandemic did not have a noticeable impact on the history of drug approval by the FDA: in particular, there were no peaks in approvals of antimicrobial and antiviral drugs or drugs for the treatment of respiratory diseases. Between 2019 and 2023, the FDA approved only a few drugs for the treatment of COVID-19: in 2020 — remdesivir (Veklury®; an antiviral drug for the treatment of COVID-19)[348], in 2021 — nirmatrelvir+ritonavir (Paxlovid®; an antiviral drug for the treatment of COVID-19, previously approved under the emergency use program, received full approval)[349]. The FDA has not approved any other drugs specifically for the treatment of COVID-19. The main focus in these years was on the development and approval of vaccines against COVID-19, which are not within the purview of the Center for Drug Evaluation and Research (CDER) of the FDA, but are approved by the Center for Biologics Evaluation and Research (CBER). Thus, to date, the FDA has approved only two drugs for the treatment of COVID-19 — remdesivir[350] and the combination nirmatrelvir + ritonavir[351]. Both are antiviral agents aimed at suppressing the replication of the SARS-CoV-2 virus.

Trends

An analysis of FDA-approved drugs from 2012 to 2024 reveals several significant trends and innovations that are shaping the future of drug development [18–20]:

Shift towards biotechnology. There is a noticeable increase in the number of approved biotechnology drugs (including monoclonal antibodies and gene therapy methods). This trend reflects a growing focus on personalized medicine and the treatment of rare diseases.

Continued priority for oncology research. Anti-cancer drugs have consistently represented a significant portion of approvals. The emergence of innovative approaches, such as CAR-T therapy (e.g., tisagenlecleucel)[352] and targeted therapy (e.g., ceritinib, nivolumab)[353, 354], demonstrates the rapid development of this field.

[337] Drugs.com. Mounjaro. Available from: https://www.drugs.com/mounjaro.html
[338] Drugs.com. Zepbound. Available from: https://www.drugs.com/zepbound.html
[339] Drugs.com. Nuedexta. Available from: https://www.drugs.com/nuedexta.html
[340] Drugs.com. Rexulti. Available from: https://www.drugs.com/rexulti.html
[341] Drugs.com. Vraylar. Available from: https://www.drugs.com/vraylar.html
[342] Drugs.com. Aimovig. Available from: https://www.drugs.com/aimovig.html
[343] Drugs.com. Aduhelm. Available from: https://www.drugs.com/aduhelm.html
[344] Drugs.com. Lecanemab. Available from: https://www.drugs.com/lecanemab.html
[345] Drugs.com. Donanemab. Available from: https://www.drugs.com/donanemab.html
[346] Drugs.com. Brineura. Available from: https://www.drugs.com/brineura.html
[347] Drugs.com. Cerezyme. Available from: https://www.drugs.com/cerezyme.html
[348] Drugs.com. Veklury. Available from: https://www.drugs.com/veklury.html
[349] Drugs.com. Paxlovid. Available from: https://www.drugs.com/paxlovid.html
[350] Drugs.com. Veklury. Available from: https://www.drugs.com/veklury.html
[351] Drugs.com. Paxlovid. Available from: https://www.drugs.com/paxlovid.html
[352] Drugs.com. Kymriah. Availalble from: https://www.drugs.com/kymriah.html
[353] Drugs.com. Zykadia. Availalble from: https://www.drugs.com/zykadia.html
[354] Drugs.com. Opdivo. Availalble from: https://www.drugs.com/opdivo.html

ОБЗОР
DOI: 10.19163/2307-9266-2025-13-6-432-486

Focus on rare diseases. A significant portion of approvals has been directed towards rare, or orphan diseases, indicating a strategic shift towards addressing unmet needs of small patient groups. This trend is consistent with growing investor interest and the possibility of accelerated approval. There is significantly less competition in this area. Thus, startups or young pharmaceutical or research companies have a chance to attract investment and create an innovative product.

New therapeutic approaches. Several innovative treatments have emerged and developed during this period:

- RNA interference (siRNA) therapy (e.g., nedosiran)[355];
- gene therapy (e.g., onasemnogene abeparvovec, lovotibeglogene autotemcel)[356, 357];
- cell therapy (e.g., donaisel for type 1 diabetes)[358];
- bispecific antibodies and antibody-drug conjugates;
- the emergence of promising areas in the fight against infectious diseases.

Progress in the treatment of neurodegenerative diseases. The approval of drugs aimed at treating Alzheimer's disease (e.g., the combination of aducanumab, lecanemab)[359, 360] represents a significant milestone, despite ongoing debates about their effectiveness and economic feasibility.

Innovations in the field of metabolic disorders. New approaches in the treatment of diabetes and obesity (e.g., SGLT2 inhibitors, GLP-1 receptor agonists, dual incretin receptor agonists) have led to significant progress in the treatment of these pathologies.

Rapid response to new threats. The rapid development and approval of drugs for the treatment of COVID-19 (e.g., remdesivir, the combination of nirmatrelvir + ritonavir)[361, 362] demonstrated the industry's ability to respond quickly to global challenges.

Repurposing of known drugs. The approval of drugs such as sildenafil for the treatment of pulmonary hypertension[363] and cantharidin for molluscum contagiosum[364] highlights the possibility of repurposing known drugs.

Achievements in personalized medicine. There has been an increase in the number of approvals for targeted therapies based on specific genetic or molecular profiles, which not only contributes to the development of the personalized medicine paradigm, but is in fact its debut.

Innovative drug delivery systems. The approval of new dosage forms and delivery systems (e.g., levetiracetam[365]; the first 3D-printed drug for the treatment of epilepsy) indicates ongoing efforts to improve patient adherence to treatment and increase the effectiveness of therapy.

These trends point to several promising directions for future drug development:

- further research into gene and cell therapy for a wider range of diseases;
- continued development of targeted therapy in oncology;
- expanding the use of siRNA and other nucleic acid-based therapeutics;
- increased attention to neurodegenerative diseases using knowledge gained from recent breakthroughs;
- development of combination therapy and multi-targeted drugs;
- studying the microbiome and its therapeutic potential;
- complexification of drug delivery systems and dosage forms.

Figure 14 shows the distribution of the proportions of drugs of various ATC classes during the study period. The proportion of drugs in category L — antineoplastic and immunomodulatory agents — remains the most numerous among all registrations. A trend line with an R^2 value of 0.673 and a high trend significance ($p < 0.001$) has been added to the figure. Thus, the contribution of time to the increase in the proportion

[355] Drugs.com. Rivfloza. Availalble from: https://www.drugs.com/rivfloza.html
[356] Drugs.com. Zolgensma. Availalble from: https://www.drugs.com/zolgensma.html
[357] Drugs.com. Lyfgenia. Availalble from: https://www.drugs.com/lyfgenia.html
[358] Drugs.com. Lantidra. Availalble from: https://www.drugs.com/lantidra.html
[359] Drugs.com. Aduhelm. Availalble from: https://www.drugs.com/aduhelm.html
[360] Drugs.com. Leqembi. Availalble from: https://www.drugs.com/leqembi.html
[361] Drugs.com. Veklury. Availalble from: https://www.drugs.com/veklury.html
[362] Drugs.com. Paxlovid Availalble from: https://www.drugs.com/paxlovid.html
[363] Drugs.com. Liqrev. Availalble from: https://www.drugs.com/liqrev.html
[364] Drugs.com. Ycanth. Availalble from: https://www.drugs.com/ycanth.html
[365] Drugs.com. Spritam. Availalble from: https://www.drugs.com/spritam.html

of drugs in class L is 67.3%, which is a fairly high figure. The resulting linear equation with a slope of 0.0174 suggests that the increase in the proportion of drugs in this class will be 1.74% per year. Thus, despite the fact that this scenario is difficult to consider realistic; in 10 years it is possible to increase the share of drugs in class L on the pharmaceutical market by 17.4%.

Since most anti-cancer drugs are monoclonal antibodies in terms of production method, there is a clear trend of increasing drugs of biological origin. The trend line obtained and shown in Figure 15 indicates this dynamics. The linear model with a coefficient of $R^2 = 0.55$ with a high trend significance ($p < 0.01$) indicates that the contribution of time to the variation of the data is 55%, that is, the trend can be considered stable. The resulting trend line equation $y = 0.0138x + (-27.596)$ has a slope of 0.0138, which implies that the number of biological drugs is increasing by 1.38% per year. Thus, in just 10 years, an increase in the share of biological drugs by approximately 13% can be expected. The results reflect the transition of the pharmaceutical industry to the complexification of both the drugs themselves and the methods of treatment: from small molecules to antibodies, enzyme preparations and gene therapy.

Reasons for registering developments

Figure 16 shows a diagram of the accumulation of registrations from 2013 to 2024. The largest number of registrations for the specified period occurred in 2017. It can be noted that the increase in registrations is justified by a large number of re-registrations, and the number of original drugs is no more than in 2018 and 2019. The largest number of original drugs was registered in 2021, although the absolute number of registrations in this year is quite small.

As can be seen from the presented data and in Figure 17, the registration of an original drug (the US market is traditionally focused on original drugs) is the main reason for FDA approvals [28]. In 2015, the share of new combinations in the registration structure reached its peak in the covered period and amounted to 19.4% and has been declining since then. The registration of new dosage forms accounted for a quarter of all new registrations in the period from 2016 to 2018, after which this value gradually decreased, and in 2024 the share of new combinations in the structure of drug registration is 13.9%. It is important to note the albeit small, but clearly growing in recent years share of known drugs that have received a new indication. Repurposing drugs for new indications, as has been repeatedly noted, remains a promising tactic for pharmaceutical development [87–90].

Limitations of the study

The study has several important limitations that may affect the interpretation and generalization of the results.

Limited by FDA data. The study is based on FDA data covering drug approvals issued primarily for the US market. This means that the study does not take into account approvals by other regulatory authorities (e.g., EMA in Europe, PMDA in Japan, and TGA in Australia).

Difficulties in classifying drugs. Systematization of approvals by categories, for example, by novelty or method of production (biological, synthetic drugs), is sometimes difficult due to the overlap of categories, such as biosimilars, generics and hybrid drugs with partially unique properties. These classification difficulties can lead to errors in statistics and reduce the accuracy of the analysis of individual categories.

Changing regulatory conditions. During the period under review, FDA policies and approval criteria changed, including accelerated approval programs for orphan drugs, cancer drugs, and drugs for serious diseases with high unmet demand. Such changes could affect the dynamics of approvals and create difficulties in assessing long-term trends without taking into account changes in regulation.

Impact of the COVID-19 pandemic. The COVID-19 pandemic in 2020–2022 influenced the priorities of drug development and the process of their approval, including the creation of accelerated procedures for antiviral drugs and vaccines, which could potentially slow down or postpone the approval of other therapeutic agents that were not related to the pandemic, making this time period less representative when analyzing the entire observation period (from 2013 to 2024).

Observation period. Despite the fact that the ten-year period covers a significant number of approvals, for some innovative therapies, such as gene and cell technologies. This time may not be sufficient for a complete analysis of their potential and long-

ОБЗОР
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term effects. Such new approaches require longer observations to accurately assess their impact on clinical practice and public health.

Lack of data on failed drugs. The study focuses on approved drugs and does not take into account drugs that have not passed clinical trials or have not been approved. This "survivorship bias" can distort the perception of successful drug development strategies.

Limited availability of post-registration data. The work does not assess the safety profile of new drugs, including side effects and risks. The study does not consider post-marketing studies or long-term safety profiles of approved drugs, including information on rare side effects, effectiveness in different populations and the duration of the clinical effect.

CONCLUSION

The analysis of FDA drug approvals from 2013 to 2024 revealed consistent trends and key directions in modern drug development. During this period, there has been a steady approval of small molecule drugs and an increase in the proportion of innovative approaches aimed at addressing complex therapeutic challenges or treating previously incurable pathologies, including oncological, neurological, orphan, and metabolic diseases. Progress in the development of biotechnological methods, such as monoclonal antibodies, gene therapy, and RNA interference therapy, indicates a significant shift towards personalized and targeted approaches aimed not only at eliminating symptoms but also at altering the pathogenesis of the disease.

Thus, the use of monoclonal antibodies for the treatment of cancer and inflammatory diseases demonstrates their high therapeutic value, contributing to improved survival and quality of life for patients. For example, drugs aimed at blocking immune checkpoints (PD-1, PD-L1 inhibitors) have become the basis of therapy for patients with aggressive forms of oncological diseases, which indicates the continued relevance of these areas in research.

There is a persistent interest in drugs for the treatment of oncological, metabolic, and inflammatory diseases, i.e., those diseases whose prevalence is comparable to the scale of epidemics.

Notably, despite the COVID-19 pandemic, which significantly stimulated rapid vaccine development, the FDA approved a limited number of antiviral drugs specifically designed for COVID-19.

The analysis also highlights a relatively stable level of generic approvals, while the improvement of dosage forms and combinations of existing molecules were a priority for meeting the specific needs of patients.

In addition, the growing influence of biotechnology startups on the drug development process, along with large investments from venture capital, suggests a paradigm shift in drug development from traditional synthetic compounds to more advanced (in certain respects; selectivity and safety) biological solutions. Synthetic drugs for the treatment of infections of all kinds also demonstrate a trend towards increased research, development, and implementation.

Thus, the conclusion on the trends and results of FDA approvals over more than a decade emphasizes a high orientation towards biotechnological methods, personalized medicine, treatment of oncological and orphan diseases, which is confirmed not only by the stability of approvals in these categories but also by constant improvements in their effectiveness and specificity. These trends define promising directions for future research and development, making it possible to further expand the capabilities of modern medicine in addressing complex, severe, and rare diseases that until recently were considered difficult to treat or incurable. At the same time, the high cost of many new treatments remains a major problem, as well as the lack of data on their effectiveness and safety with long-term use.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS CONTRIBUTION

Denis V. Kurkin — idea and planning of the work, design of graphic material, editing of the final version of the manuscript; Nazar A. Osadchenko, Dmitry A. Bakulin, Evgeny I. Morkovin, Sergey A. Voskresensky,

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REFERENCES

1. Stegemann S, Sheehan L, Rossi A, Barrett A, Paudel A, Crean A, Ruiz F, Bresciani M, Liu F, Shariff Z, Shine M, Schmelzer C, Pense-Lheritier AM. Rational and practical considerations to guide a target product profile for patient-centric drug product development with measurable patient outcomes – A proposed roadmap. Eur J Pharm Biopharm. 2022;177:81-88. DOI: 10.1016/j.ejpb.2022.06.006
2. Menditto E, Orlando V, De Rosa G, Minghetti P, Musazzi UM, Cahir C, Kurczewska-Michalak M, Kardas P, Costa E, Sousa Lobo JM, Almeida IF. Patient Centric Pharmaceutical Drug Product Design-The Impact on Medication Adherence. Pharmaceutics. 2020;12(1):44. DOI: 10.3390/pharmaceutics12010044
3. Usman M, Khadka S, Saleem M, Rasheed H, Kunwar B, Ali M. Pharmacometrics: A New Era of Pharmacotherapy and Drug Development in Low- and Middle-Income Countries. Adv Pharmacol Pharm Sci. 2023;2023:3081422. DOI: 10.1155/2023/3081422
4. Dugger SA, Platt A, Goldstein DB. Drug development in the era of precision medicine. Nat Rev Drug Discov. 2018;17(3):183-96. DOI: 10.1038/nrd.2017.226
5. Sertkaya A, Beleche T, Jessup A, Sommers BD. Costs of Drug Development and Research and Development Intensity in the US, 2000-2018. JAMA Netw Open. 2024;7(6):e2415445. DOI: 10.1001/jamanetworkopen.2024.15445
6. Seoane-Vazquez E, Rodriguez-Monguio R, Powers JH 3rd. Analysis of US Food and Drug Administration new drug and biologic approvals, regulatory pathways, and review times, 1980-2022. Sci Rep. 2024;14(1):3325. DOI: 10.1038/s41598-024-53554-7
7. Parvathaneni V, Kulkarni NS, Muth A, Gupta V. Drug repurposing: a promising tool to accelerate the drug discovery process. Drug Discov Today. 2019;24(10):2076-85. DOI: 10.1016/j.drudis.2019.06.014
8. Algorri M, Cauchon NS, Christian T, O'Connell C, Vaidya P. Patient-Centric Product Development: A Summary of Select Regulatory CMC and Device Considerations. J Pharm Sci. 2023;112(4):922-36. DOI: 10.1016/j.xphs.2023.01.029
9. Petrov VI, Tyurenkov IN, Kurkin DV. From Molecule to Drug. Pharmaceutical Logistics Approach. Annals of the Russian Academy of Medical Sciences. 2023;78(1):53–61. DOI: 10.15690/vramn2237
10. Kurkin DV, Osadchenko NA, Makarova AR, Galkina DA, Bakulin DA, Shatalova OV, Strygin AV, Petrov VI, Marincheva OV, Gorbunova YuV, Kolosov YuA, Zaborovsky AV, Yunina DV, Koryanova KN, Morkovin EI, Dzhavakhyan MA, Zvereva VI, Drai RV, Makarenko IE, Shuvaeva AS. Original drugs approved by the Food and Drug Administration (Center for Drug Evaluation and Research) in 2024. Pharmacy & Pharmacology. 2024;12(6):431-70. DOI: 10.19163/2307-9266-2024-12-6-431-470
11. Hughes JP, Rees S, Kalindjian SB, Philpott KL. Principles of early drug discovery. Br J Pharmacol. 2011;162(6):1239-49. DOI: 10.1111/j.1476-5381.2010.01127.x
12. Singh N, Vayer P, Tanwar S, Poyet J-L, Tsaioun K, Villoutreix BO. Drug discovery and development: introduction to the general public and patient groups. Front. Drug Discov. 2023;3:1201419. DOI: 10.3389/fddsv.2023.1201419
13. van Overbeeke E, Whichello C, Janssens R, Veldwijk J, Cleemput I, Simoens S, Juhaeri J, Levitan B, Kübler J, de Bekker-Grob E, Huys I. Factors and situations influencing the value of patient preference studies along the medical product lifecycle: a literature review. Drug Discov Today. 2019;24(1):57-68. DOI: 10.1016/j.drudis.2018.09.015
14. Vargason AM, Anselmo AC, Mitragotri S. The evolution of commercial drug delivery technologies. Nat Biomed Eng. 2021;5(9):951-67. DOI: 10.1038/s41551-021-00698-w
15. Ledley FD, McCoy SS, Vaughan G, Cleary EG. Profitability of Large Pharmaceutical Companies Compared With Other Large Public Companies. JAMA. 2020;323(9):834-843. DOI: 10.1001/jama.2020.0442
16. Brown DG, Wobst HJ. Analysis of orphan designation status for FDA approved drugs, and case studies in oncology, neuroscience and metabolic diseases. Bioorg Med Chem. 2023;80:117170. DOI: 10.1016/j.bmc.2023.117170
17. Miller KL, Fermaglich LJ, Maynard J. Using four decades of FDA orphan drug designations to describe trends in rare disease drug development: substantial growth seen in development of drugs for rare oncologic, neurologic, and pediatric-onset diseases. Orphanet J Rare Dis. 2021;16(1):265. DOI: 10.1186/s13023-021-01901-6
18. Raut G, Sharma S. Trends in FDA drug approvals: 2021–2024 insights & innovations. Ann Pharm Fr. 2025:S0003-4509(25)00106-3. DOI: 10.1016/j.pharma.2025.06.004
19. Schuhmacher A, Gassmann O, Hinder M, Hartl D. Comparative analysis of FDA approvals by top 20 pharma companies (2014-2023). Drug Discov Today. 2024;29(9):104128. DOI: 10.1016/j.drudis.2024.104128
20. Misra S, Shukla AK. FDA Novel Approvals of Pharmaceuticals, 2013-2022: An Observational Study. Applied Drug Research, Clinical Trials and Regulatory Affairs. 2024;11:e2667337. DOI: 10.2174/0126673371337155241113024436
21. Richardson PG, Mark TM, Lacy MQ. Pomalidomide: new

immunomodulatory agent with potent antiproliferative effects. Crit Rev Oncol Hematol. 2013;88 Suppl 1:S36-44. DOI: 10.1016/j.critrevonc.2013.02.001

22. Parhofer KG. Mipomersen: evidence-based review of its potential in the treatment of homozygous and severe heterozygous familial hypercholesterolemia. Core Evid. 2012;7:29-38. DOI: 10.2147/CE.S25239
23. Robson RD. Modification of the cardiovascular effects of L-dopa in anesthetized dogs by inhibitors of enzymes involved in catecholamine metabolism. Circ Res. 1971;28(6):662-70. DOI: 10.1161/01.res.28.6.662
24. Leppert W, Woron J. The role of naloxegol in the management of opioid-induced bowel dysfunction. Therap Adv Gastroenterol. 2016;9(5):736-46. DOI: 10.1177/1756283X16648869
25. Campbell WC. History of avermectin and ivermectin, with notes on the history of other macrocyclic lactone antiparasitic agents. Curr Pharm Biotechnol. 2012;13(6):853-65. DOI: 10.2174/138920112800399095
26. El-Saber Batiha G, Alqahtani A, Ilesanmi OB, Saati AA, El-Mleeh A, Hetta HF, Magdy Beshbishy A. Avermectin Derivatives, Pharmacokinetics, Therapeutic and Toxic Dosages, Mechanism of Action, and Their Biological Effects. Pharmaceuticals (Basel). 2020;13(8):196. DOI: 10.3390/ph13080196
27. Kanski JJ. Carbonic anhydrase inhibitors and osmotic agents in glaucoma. Carbonic anhydrase inhibitors. Br J Ophthalmol. 1968;52(8):642–3. DOI: 10.1136/bjo.52.8.642
28. Rucquoy M, Sorel L. Diclofenamide in the treatment of therapy-resistant epilepsy. Acta Neurol Belg. 1978;78(3):174-82.
29. Lim KR, Maruyama R, Yokota T. Eteplirsen in the treatment of Duchenne muscular dystrophy. Drug Des Devel Ther. 2017;11:533-45. DOI: 10.2147/DDDT.S97635
30. Hoy SM. Nusinersen: A Review in 5q Spinal Muscular Atrophy. CNS Drugs. 2021;35(12):1317-1328. DOI: 10.1007/s40263-021-00878-x Erratum in: CNS Drugs. 2022;36(1):99. DOI: 10.1007/s40263-021-00889-8
31. Yuen KCJ. Growth Hormone Stimulation Tests in Assessing Adult Growth Hormone Deficiency. [Updated 2023 Aug 8]. In: Feingold KR, Ahmed SF, Anawalt B, et al., editors. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; 2000. Available from: https://www.ncbi.nlm.nih.gov/books/NBK395585/
32. Chabicovsky M, Winkler S, Soeberdt M, Kilic A, Masur C, Abels C. Pharmacology, toxicology and clinical safety of glycopyrrolate. Toxicol Appl Pharmacol. 2019;370:154-69. DOI: 10.1016/j.taap.2019.03.016
33. Mwacalimba K, Sheehy J, Adolph C, Savadelis M, Kryda K, Poulsen Nautrup B. A review of moxidectin vs. other macrocyclic lactones for prevention of heartworm disease in dogs with an appraisal of two commercial formulations. Front Vet Sci. 2024;11:1377718. DOI: 10.3389/fvets.2024.1377718
34. Chen C, Wu D, Guo Z, Xie Q, Reinhart GJ, Madan A, Wen J, Chen T, Huang CQ, Chen M, Chen Y, Tucci FC, Rowbottom M, Pontillo J, Zhu YF, Wade W, Saunders J, Bozigian H, Struthers RS. Discovery of sodium R-(+)-4-{2-[5-(2-fluoro-3-methoxyphenyl)-3-(2-fluoro-6-[trifluoromethyl]benzyl)-4-methyl-2,6-dioxo-3,6-dihydro-2H-pyrimidin-1-yl]-1-phenylethylamino}butyrate (elagolix), a potent and orally available nonpeptide antagonist of the human gonadotropin-releasing hormone receptor. J Med Chem. 2008;51(23):7478-85. DOI: 10.1021/jm8006454
35. Baksheeva VE, La Rocca R, Allegro D, Derviaux C, Pasquier E, Roche P, Morelli X, Devred F, Golovin AV, Tsvetkov PO. NanoDSF Screening for Anti-tubulin Agents Uncovers New Structure–Activity Insights. Journal of Medicinal Chemistry. 2025;68(16): 17485–98. DOI: 10.1021/acs.jmedchem.5c01008
36. Diviccaro S, Cioffi L, Falvo E, Giatti S, Melcangi RC. Allopregnanolone: An overview on its synthesis and effects. J Neuroendocrinol. 2022;34(2):e12996. DOI: 10.1111/jne.12996
37. Dhillon S, Keam SJ. Bremelanotide: First Approval. Drugs. 2019;79(14):1599-606. DOI: 10.1007/s40265-019-01187-w
38. Böhm M, Robert C, Malhotra S, Clément K, Farooqi S. An overview of benefits and risks of chronic melanocortin-1 receptor activation. J Eur Acad Dermatol Venereol. 2025;39(1):39-51. DOI: 10.1111/jdv.20269
39. Thakare R, Dasgupta A, Chopra S. Pretomanid for the treatment of pulmonary tuberculosis. Drugs Today (Barc). 2020;56(10):655-68. DOI: 10.1358/dot.2020.56.10.3161237
40. Jacobs JW, Leadbetter MR, Bell N, Koo-McCoy S, Carreras CW, He L, Kohler J, Kozuka K, Labonté ED, Navre M, Spencer AG, Charmot D. Discovery of Tenapanor: A First-in-Class Minimally Systemic Inhibitor of Intestinal Na+/H+ Exchanger Isoform 3. ACS Med Chem Lett. 2022;13(7):1043-51. DOI: 10.1021/acsmedchemlett.2c00037
41. Calcaterra NE, Barrow JC. Classics in chemical neuroscience: diazepam (valium). ACS Chem Neurosci. 2014;5(4):253-60. DOI: 10.1021/cn5000056
42. Davis HR, Veltri EP. Zetia: inhibition of Niemann-Pick C1 Like 1 (NPC1L1) to reduce intestinal cholesterol absorption and treat hyperlipidemia. J Atheroscler Thromb. 2007;14(3):99-108. DOI: 10.5551/jat.14.99
43. Campolo M, Casili G, Biundo F, Crupi R, Cordaro M, Cuzzocrea S, Esposito E. The Neuroprotective Effect of Dimethyl Fumarate in an MPTP-Mouse Model of Parkinson's Disease: Involvement of Reactive Oxygen Species/Nuclear Factor-κB/Nuclear Transcription Factor Related to NF-E2. Antioxid Redox Signal. 2017;27(8):453–71. DOI: 10.1089/ars.2016.6800
44. Hoogendoorn A, Avery TD, Li J, Bursill C, Abell A, Grace PM. Emerging Therapeutic Applications for Fumarates. Trends Pharmacol Sci. 2021;42(4):239-54. DOI: 10.1016/j.tips.2021.01.004
45. Cook T, Sheridan WP. Development of GnRH antagonists for prostate cancer: new approaches to treatment. Oncologist. 2000;5(2):162-8. DOI: 10.1634/theoncologist.5-2-162
46. Haefely W. Benzodiazepine interactions with GABA receptors. Neurosci Lett. 1984;47(3):201-6. DOI: 10.1016/0304-3940(84)90514-7
47. Roshmi RR, Yokota T. Pharmacological Profile of Viltolarsen for the Treatment of Duchenne Muscular Dystrophy: A Japanese Experience. Clin Pharmacol. 2021;13:235-42. DOI: 10.2147/CPAA.S288842
48. Haws R, Brady S, Davis E, Fletty K, Yuan G, Gordon G, Stewart M, Yanovski J. Effect of setmelanotide, a melanocortin-4 receptor agonist, on obesity in Bardet-Biedl syndrome. Diabetes Obes Metab. 2020;22(11):2133-40. DOI: 10.1111/dom.14133

49. Kievit P, Halem H, Marks DL, Dong JZ, Glavas MM, Sinnayah P, Pranger L, Cowley MA, Grove KL, Culler MD. Chronic treatment with a melanocortin-4 receptor agonist causes weight loss, reduces insulin resistance, and improves cardiovascular function in diet-induced obese rhesus macaques. Diabetes. 2013;62(2):490-7. DOI: 10.2337/db12-0598

50. Chen KY, Muniyappa R, Abel BS, Mullins KP, Staker P, Brychta RJ, Zhao X, Ring M, Psota TL, Cone RD, Panaro BL, Gottesdiener KM, Van der Ploeg LH, Reitman ML, Skarulis MC. RM-493, a melanocortin-4 receptor (MC4R) agonist, increases resting energy expenditure in obese individuals. J Clin Endocrinol Metab. 2015;100(4):1639-45. DOI: 10.1210/jc.2014-4024

51. Keam SJ. Vibegron: First Global Approval. Drugs. 2018;78(17):1835-1839. DOI: 10.1007/s40265-018-1006-3

52. Shamsudeen I, McCrindle BW, Hegele RA. Treatment of Homozygous Familial Hypercholesterolemia With ANGPTL3 Inhibitor, Evinacumab. JCEM Case Rep. 2023;1(3):luad058. DOI: 10.1210/jcemcr/luad058

53. Assefa M, Gepfert A, Zaheer M, Hum JM, Skinner BW. Casimersen (AMONDYS 45™): An Antisense Oligonucleotide for Duchenne Muscular Dystrophy. Biomedicines. 2024;12(4):912. DOI: 10.3390/biomedicines12040912

54. Findling RL, Candler SA, Nasser AF, Schwabe S, Yu C, Garcia-Olivares J, O'Neal W, Newcorn JH. Viloxazine in the Management of CNS Disorders: A Historical Overview and Current Status. CNS Drugs. 2021;35(6):643-53. DOI: 10.1007/s40263-021-00825-w

55. McCarty J, Cassie D, Kodihalli S, Aigbedo E, Tian J, Yeo K, Komlenovic V, Charles L, Drobic B, Warnock B. Brincidofovir in the Era of Mpox. Expert Rev Anti Infect Ther. 2025;23(9):781-96. DOI: 10.1080/14787210.2025.2532029

56. Yi S, Kim I, Hager R, Strazzeri MM, Garrard L, Matsubayashi T, Mehta R. Food and Drug Administration Approval Summary: Odevixibat (Bylvay) for the Treatment of Pruritus With Progressive Familial Intrahepatic Cholestasis. Gastro Hep Adv. 2024;4(4):100596. DOI: 10.1016/j.gastha.2024.100596

57. Angelini C. Evaluating avalglucosidase alfa for the management of late-onset Pompe disease. Expert Rev Neurother. 2024;24(3):259-66. DOI: 10.1080/14737175.2024.2306855

58. Kamihara J, Hamilton KV, Pollard JA, Clinton CM, Madden JA, Lin J, Imamovic A, Wall CB, Wassner AJ, Weil BR, Heeney MM, Vargas SO, Kaelin WG Jr, Janeway KA, Perini RF, Zojwalla NJ, Voss SD, DuBois SG. Belzutifan, a Potent HIF2α Inhibitor, in the Pacak-Zhuang Syndrome. N Engl J Med. 2021;385(22):2059-65. DOI: 10.1056/NEJMoa2110051

59. Viscusi ER, Torjman MC, Munera CL, Stauffer JW, Setnik BS, Bagal SN. Effect of difelikefalin, a selective kappa opioid receptor agonist, on respiratory depression: A randomized, double-blind, placebo-controlled trial. Clin Transl Sci. 2021;14(5):1886-93. DOI: 10.1111/cts.13042

60. Fishbane S, Jamal A, Munera C, Wen W, Menzaghi F; KALM-1 Trial Investigators. A Phase 3 Trial of Difelikefalin in Hemodialysis Patients with Pruritus. N Engl J Med. 2020;382(3):222-32. DOI: 10.1056/NEJMoa1912770

61. Phan NQ, Lotts T, Antal A, Bernhard JD, Ständer S. Systemic kappa opioid receptor agonists in the treatment of chronic pruritus: a literature review. Acta Derm Venereol. 2012;92(5):555-60. DOI: 10.2340/00015555-1353

62. Levien TL, Baker DE. Avacopan. Hosp Pharm. 2023;58(2):134-142. DOI: 10.1177/00185787221087187

63. Howley E, Davies EG, Kreins AY. Congenital Athymia: Unmet Needs and Practical Guidance. Ther Clin Risk Manag. 2023;19:239-54. DOI: 10.2147/TCRM.S379673

64. Hays JT, Ebbert JO. Varenicline for tobacco dependence. N Engl J Med. 2008;359(19):2018-24. DOI: 10.1056/NEJMct0800146

65. Wagner SM, Melchardt T, Greil R. Ropeginterferon alfa-2b for the treatment of patients with polycythemia vera. Drugs Today (Barc). 2020;56(3):195-202. DOI: 10.1358/dot.2020.56.3.3107706

66. Jones HL, Nania TI, Moore JM, Reed JD, Lyons AW, Potter P, Ashurst J, Holley H. Vosoritide (Voxzogo) for Achondroplasia: A Review of Clinical and Real-World Evidence. Cureus. 2025;17(7):e87983. DOI: 10.7759/cureus.87983

67. Saunders RN, Metcalfe MS, Nicholson ML. Rapamycin in transplantation: a review of the evidence. Kidney Int. 2001;59(1):3-16. DOI: 10.1046/j.1523-755.2001.00460.x

68. Migliorati JM, Jin J, Zhong XB. siRNA drug Leqvio (inclisiran) to lower cholesterol. Trends Pharmacol Sci. 2022;43(5):455-456. DOI: 10.1016/j.tips.2022.02.003

69. Patra S, Dutta D, Nagendra L, Raizada N. Efficacy and Safety of Levoketoconazole in Managing Cushing's Syndrome: A Systematic Review. Indian J Endocrinol Metab. 2024;28(4):343-9. DOI: 10.4103/ijem.ijem_477_23

70. Shirley M. Faricimab: First Approval. Drugs. 2022;82(7):825-830. DOI: 10.1007/s40265-022-01713-3

71. Al-Samkari H, van Beers EJ. Mitapivat, a novel pyruvate kinase activator, for the treatment of hereditary hemolytic anemias. Ther Adv Hematol. 2021;12:20406207211066070. DOI: 10.1177/20406207211066070

72. Al-Mahrouqi T, Al Alawi M, Freire RC. Dexmedetomidine in the Treatment of Depression: An Up-to-date Narrative Review. Clin Pract Epidemiol Ment Health. 2023;19:e174501792307240. DOI: 10.2174/17450179-v19-230823-2023-4

73. Di Martino RMC, Maxwell BD, Pirali T. Deuterium in drug discovery: progress, opportunities and challenges. Nat Rev Drug Discov. 2023;22(7):562-84. DOI: 10.1038/s41573-023-00703-8

74. Novograd J, Frishman WH. Teplizumab Therapy to Delay the Onset of Type 1 Diabetes. Cardiol Rev. 2024;32(6):572-576. DOI: 10.1097/CRD.0000000000000563

75. Shoham Y, Gasteratos K, Singer AJ, Krieger Y, Silberstein E, Goverman J. Bromelain-based enzymatic burn debridement: A systematic review of clinical studies on patient safety, efficacy and long-term outcomes. Int Wound J. 2023;20(10):4364-83. DOI: 10.1111/iwj.14308

76. Moazzam M, Zhang M, Hussain A, Yu X, Huang J, Huang Y. The landscape of nanoparticle-based siRNA delivery and therapeutic development. Mol Ther. 2024;32(2):284-312. DOI: 10.1016/j.ymthe.2024.01.005

77. Rodgers J. Human African trypanosomiasis, chemotherapy and CNS disease. J Neuroimmunol. 2009;211(1-2):16-22. DOI: 10.1016/j.jneuroim.2009.02.007

78. Ong J, Zarnegar A, Selvam A, Driban M, Chhablani J. The Complement System as a Therapeutic Target in Retinal Disease. Medicina (Kaunas). 2024;60(6):945. DOI: 10.3390/medicina60060945
79. Ciombor KK, Berlin J. Aflibercept--a decoy VEGF receptor. Curr Oncol Rep. 2014;16(2):368. DOI: 10.1007/s11912-013-0368-7
80. Makurvet FD. Biologics vs. small molecules: Drug costs and patient access. Medicine in Drug Discovery. 2021;9:100075. DOI: 10.1016/j.medidd.2020.100075
81. Goode R, Chao B. Biological patent thickets and delayed access to biosimilars, an American problem. J Law Biosci. 2022;9(2):lsac022. DOI: 10.1093/jlb/lsac022
82. Scott EC, Baines AC, Gong Y, Moore R Jr, Pamuk GE, Saber H, Subedee A, Thompson MD, Xiao W, Pazdur R, Rao VA, Schneider J, Beaver JA. Trends in the approval of cancer therapies by the FDA in the twenty-first century. Nat Rev Drug Discov. 2023;22(8):625-40. DOI: 10.1038/s41573-023-00723-4
83. Tran H, Sun D. New Advances in US FDA Approved Oncology Drugs from 2015-2023. American Journal of Pharmaceutical Education. 2024;88(9):100842. DOI: 10.1016/j.ajpe.2024.100842
84. Kudek MR, Adashek JJ, Kurzrock R. Ag(e)nostic precision oncology therapy approvals across the years. Trends Cancer. 2025;11(8):726-35. DOI: 10.1016/j.trecan.2025.04.015
85. Kurkin DV, Morkovin EI, Bakulin DA, Zaborovsky AV, Makarenko IE, Drai RV, Solodovnikov AG, Petrov VI, Koryanova KN, Lycheva NA, Voskresensky SA, Strygin AV, Kolosov YuA, Gorbunova YuV, Ivanova OV. Methodological and regulatory aspects of pharmaceutical development of biological products. Pharmacy & Pharmacology. 2023;11(5):384-98. DOI: 10.19163/2307-9266-2023-11-5-384-398
86. Kurkin DV, Morkovin EI, Bakulin DA, Gorbunova YuV, Kolosov YuA, Dzhavakhyan MA, Makarenko IE, Drai RV, Zaborovsky AV, Shatalova OV, Strygin AV, Petrov VI, Pleten AP, Prokopov AA, Tatarenko-Kozmina TYu. Overview of drugs approved by the FDA in 2022. Pharmacy & Pharmacology. 2023;11(3):193-210. DOI: 10.19163/2307-9266-2023-11-3-193-210
87. Schuhmacher A, Gassmann O, Hinder M. Changing R&D models in research-based pharmaceutical companies. J Transl Med. 2016;14(1):105. DOI: 10.1186/s12967-016-0838-4
88. Petrov VI, Osadchenko NA, Tarasov AS, Dotsenko AM, Morkovin EI. Effectiveness assessment of sulfur-containing amino acids in rats with experimental “alcohol withdrawal syndrome” with modified zoosocial interaction methods. Pharmacy & Pharmacology. 2024;12(1):4-14. DOI: 10.19163/2307-9266-2024-12-1-4-14
89. Krishnamurthy N, Grimshaw AA, Axson SA, Choe SH, Miller JE. Drug repurposing: a systematic review on root causes, barriers and facilitators. BMC Health Serv Res. 2022;22(1):970. DOI: 10.1186/s12913-022-08272-z
90. Recino A, Rayner MLD, Rohn JL, Della Pasqua O, Recino A, Rayner MLD, Rohn JL, Carter B, Cupani A, Dahlmann-Noor A, Foltynie T, Furman J, Hobbiger S, Lugarà E, Mole SE, Orlu M, Phillips JB, Spingardi P, Della Pasqua O. Therapeutic innovation in drug repurposing: Challenges and opportunities. Drug Discov Today. 2025;30(7):104390. DOI: 10.1016/j.drudis.2025.104390.

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