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Biopharmaceuticals: A review of their development and contribution to healthcare [Produtos biofarmacêuticos: Uma análise do seu desenvolvimento e contribuição para os cuidados de saúde]
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Abstract

Biopharmaceuticals play a crucial role in preventing, treating, and diagnosing a diverse range of diseases across various medical disciplines. The market for biopharmaceuticals has experienced significant growth, driven by tremendous demand, with their dynamic market potential believed to surpass that of conventional counterparts. This review provides insight into the manufacturing process of biopharmaceuticals, covering both upstream and downstream processing. Various types of biopharmaceutical products, such as monoclonal antibodies, enzymes, vaccines, stem cells, human growth hormones, cytokines, nucleic acids, and carbohydrates, are explored alongside their respective clinical applications. The review also addresses the challenges encountered in the development, formulation, and utilization of these biopharmaceuticals. In essence, this review contributes valuable knowledge to the understanding of the expansive field of biopharmaceuticals. © 2023 ALIES. All rights reserved.

Author Keywords

Biopharmaceuticals; clinical; manufacturing; recombinant; therapeutics

Index Keywords

carbohydrate, cytokine, enzyme, human growth hormone, monoclonal antibody, nucleic acid, vaccine; downstream processing, drug formulation, drug manufacture, health care, human, nonhuman, processing, Review, stem cell, upstream processing

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References

- González Peña, O.I., López Zavala, M. Á., Cabral Ruelas, H.
Pharmaceuticals Market, Consumption Trends and Disease Incidence Are Not Driving the Pharmaceutical Research on Water and Wastewater
(2021) *International journal of environmental research and public health*, 18 (5), p. 2523.
- O'Flaherty, R., Bergin, A., Flampouri, E., Mota, L.M., Obaidi, I., Quigley, A., Xie, Y., Butler, M.
Mammalian Cell Culture for Production of Recombinant Proteins: A review of the Critical Steps in Their Biomanufacturing
(2020) *Biotechnology advances*, 1 (43), p. 107552.
- Ghanemi, K., Yan, S.
Biopharmaceutical Innovation: Benefits and Challenges
(2017) *Open access journal of science*, 1 (1), p. 00004.
- Walsh, G.
Biopharmaceutical Benchmarks 2018
(2018) *Nature biotechnology*, 36 (12), pp. 1136-1145.

- Misra, M.
Biosimilars: Current Perspectives and Future Implications
(2012) *Indian journal of Pharmacology*, 44 (1), pp. 12-14.
- Kesik-Brodacka, M.
Progress in Biopharmaceutical Development
(2018) *Biotechnology and applied biochemistry*, 65 (3), pp. 306-322.
- Skalko-Basnet, N.
Biologics: The Role of Delivery Systems in Improved Therapy
(2014) *Biologics*, 8, pp. 107-114.
- Mitragotri, S., Burke, P.A., Langer, R.
Overcoming the Challenges in Administering Biopharmaceuticals: Formulation and Delivery Strategies
(2014) *Nature reviews drug discovery*, 13 (9), pp. 655-672.
- Gronemeyer, P., Ditz, R., Strube, J.
Trends in Upstream and Downstream Process Development for Antibody Manufacturing
(2014) *Bioengineering (Basel)*, 1 (4), pp. 188-212.
- Jozala, A.F., Geraldés, D.C., Tundisi, L.L., Feitosa, V.A., Breyer, C.A., Cardoso, S.L., Mazzola, P.G., de Oliveira, M.A.
Biopharmaceuticals from Microorganisms: From Production to Purification
(2016) *Brazilian journal of microbiology*, 47, pp. 51-63.
Jr A.P. (Suppl 1)
- Tavares, A.P.M., Neves, M.C., Trindade, T., Freire, M
Recovery and Purification of (Bio)Pharmaceuticals Using (Nano) Materials
(2020) *Recent advances in analytical techniques*, 4, pp. 58-93.
G
- Zhang, Z.X., Nong, F.T., Wang, Y.Z., Yan, C.X., Gu, Y., Song, P., Sun, X.-M.
Strategies for Efficient Production of Recombinant Proteins in Escherichia coli: Alleviating the Host Burden and Enhancing Protein Activity
(2022) *Microbial cell factories*, 21 (1), p. 191.
- Bhatwa, A., Wang, W., Hassan, Y.I., Abraham, N., Li, X.Z., Zhou, T.
Challenges Associated With the Formation of Recombinant Protein Inclusion Bodies in Escherichia coli and Strategies to Address Them for Industrial Applications
(2021) *Frontiers in bioengineering and biotechnology*, 9, p. 630551.
- Baeshen, N.A., Baeshen, M.N., Sheikh, A., Bora, R.S., Ahmed, M.M., Ramadan, H.A., Saini, K.S., Redwan, E.M.
Cell Factories for Insulin Production
(2014) *Microbial cell factories*, 13, p. 141.
- Hou, J., Tyo, K.E.J., Liu, Z., Petranovic, D., Nielsen, J.
Metabolic Engineering of Recombinant Protein Secretion by *Saccharomyces cerevisiae*
(2014) *FEMS yeast research*, 12 (5), pp. 491-510.
- Polez, S., Origi, D., Zahariev, S., Guarnaccia, C., Tisminetzky, S.G., Skoko, N., Baralle, M.
A Simplified and Efficient Process for Insulin Production in *Pichia pastoris*
(2016) *PLoS one*, 11 (12), p. e0167207.
- Nielsen, J.
Production of Biopharmaceutical Proteins By Yeast: Advances Through Metabolic

Engineering

(2013) *Bioengineered*, 4 (4), pp. 207-211.

- Kantargjieff, A., Zhou, W.
Mammalian Cell Cultures for Biologics Manufacturing Preface
(2013) *Advance in biochemical engineering and biotechnology*, 139, pp. 1-9.
- Dumont, J., Ewart, D., Mei, B., Estes, S., Kshirsagar, R.
Human Cell Lines for Biopharmaceutical Manufacturing: History, Status, and Future Perspectives
(2016) *Critical reviews in biotechnology*, 36 (6), pp. 1110-1122.
- Glinšek, K., Bozovičar, K., Bratkovič, T.
CRISPR Technologies in Chinese Hamster Ovary Cell Line Engineering
(2023) *International journal of molecular sciences*, 24 (9), p. 8144.
- Mitra, S., Tomar, P.C.
Hybridoma Technology; Advancements, Clinical Significance, and Future Aspects
(2021) *Journal of genetic engineering and biotechnology*, 19 (1), p. 159.
- Parray, H.A., Shukla, S., Samal, S., Shrivastava, T., Ahmed, S., Sharma, C., Kumar, R.
Hybridoma Technology A Versatile Method for Isolation of Monoclonal Antibodies, Its Applicability Across Species, Limitations, Advancement and Future Perspectives
(2020) *International immunopharmacology*, 85, p. 106639.
- Muyldermans, S., Smider, V.V.
Distinct Antibody Species: Structural Differences Creating Therapeutic Opportunities
(2016) *Current opinion in immunology*, 40, pp. 7-13.
- Weber, J., Peng, H., Rader, C.
From Rabbit Antibody Repertoires To Rabbit Monoclonal Antibodies
(2017) *Experimental & molecular medicine*, 49 (3), p. e305.
- Fields, C., Li, P., O'Mahony, J.J., Lee, G.U.
Advances in Affinity Ligand-Functionalized Nanomaterials for Biomagnetic Separation
Biotechnology & bioengineering, 113 (1), pp. 11-25.
(2106)
- Yamaguchi, H., Miyazaki, M.
Refolding Techniques for Recovering Biologically Active Recombinant Proteins from Inclusion Bodies
(2014) *Biomolecules*, 4 (1), pp. 235-251.
- Liu, H.F., Ma, J., Winter, C., Bayer, R.
Recovery and Purification Process Development for Monoclonal Antibody Production
(2010) *MAbs*, 2 (5), pp. 480-499.
- Faria, R.P.V., Rodrigues, A.E.
Instrumental Aspects of Simulated Moving Bed chromatography
(2015) *Journal of chromatography A*, 1421, pp. 82-102.
- Rosa, P.A.J., Ferreira, I.F., Azevedo, A.M., Aires-Barros, M.R.
Aqueous Two-Phase Systems: A Viable Platform in the Manufacturing of Biopharmaceuticals
(2010) *Journal of chromatography A*, 1217 (16), pp. 2296-2305.
- Dutra, G., Komuczki, D., Jungbauer, A., Satzer, P.
Continuous Capture of Recombinant Antibodies by ZnCl₂ Precipitation Without

Polyethylene Glycol

(2020) *Engineering in life sciences*, 20 (7), pp. 265-274.

- Burgstaller, D., Jungbauer, A., Satzer, P.
Continuous Integrated Antibody Precipitation With Two-Stage Tangential Flow Microfiltration Enables Constant Mass Flow
(2019) *Biotechnology and bioengineering*, 116 (5), pp. 1053-1065.
- Li, Z., Gu, Q., Coffman, J.L., Przybycien, T., Zydney, A.L.
Continuous Precipitation For Monoclonal Antibody Capture Using Countercurrent Washing by Microfiltration
(2019) *Biotechnology progress*, 235 (6), p. e2886.
- Thakur, G., Rathore, A.S.
Modelling and Optimization of Single-Pass Tangential Flow Ultrafiltration for Continuous Manufacturing of Monoclonal Antibodies
(2021) *Separation and purification technology*, 276, p. 119341.
- Chen, W., Li, X., Guo, M., Link, F.J., Ramli, S.S., Ouyang, J., Rosbottom, I., Heng, J.Y.Y.
Biopurification of Monoclonal Antibody (mAb) Through Crystallisation
(2021) *Separation and purification technology*, 263, p. 118358.
- Kruse, T., Kampmann, M., Rüdell, I., Greller, G.
An Alternative Downstream Process Based on Aqueous Two-Phase Extraction for the Purification of Monoclonal Antibodies
(2020) *Biochemical engineering journal*, 161, p. 107703.
- Ornelas-González, A., Reisenauer, S.U., González-González, M., Rito-Palomares, M.
Characterization and Optimization of Immunoaffinity Aqueous Two-Phase Systems with PEGylated CD133/2-Biotin Antibody in Route to Stem Cell Separation
(2020) *Journal of chemical technology & biotechnology*, 95 (1), pp. 123-131.
- Zanker, A.A., Stargardt, P., Kurzbach, S.C., Turrina, C., Mairhofer, J., Schwaminger, S.P., Borensmeier, C.
Direct Capture and Selective Elution of A Secreted Polyglutamate-tagged Nanobody Using Bare Magnetic Nanoparticles
(2022) *Biotechnology journal*, 17 (5), p. 2100577.
- Schwaminger, S.P., Blank-Shim, S.A., Scheifele, I., Pipich, V., Fraga-García, P., Berensmeier, S.
Design of Interactions Between Nanomaterials and Proteins: A Highly Affine Peptide Tag to Bare Iron Oxide Nanoparticles for Magnetic Protein Separation
(2019) *Biotechnology journal*, 14 (3), p. 1800055.
- Gerstweiler, L., Bi, J., Middelberg, A.P.J.
Continuous Downstream Bioprocessing for Intensified Manufacture of Biopharmaceuticals and Antibodies
(2021) *Chemical engineering science*, 231, p. 116272.
- Strube, J., Ditz, R., Kornecki, M., Huter, M., Schmidt, A., Thiess, H., Zobel-Roos, S.
Process Intensification in Biologics Manufacturing
(2018) *Chemical engineering and processing - process intensification*, 133, pp. 278-293.
- Lu, R.-M., Hwang, Y.-C., Liu, I.J., Lee, C.-C., Tsai, H.-Z., Li, H.-J., Wu, H.-C.
Development of Therapeutic Antibodies for the Treatment of Diseases
(2020) *Journal of biomedical science*, 27 (1), p. 1.
- Ryman, J.T., Meibohm, B.
Pharmacokinetics of Monoclonal Antibodies
(2017) *CPT Pharmacometrics & Systems Pharmacology*, 6 (9), pp. 576-588.

- Hu, Y., Turner, M.J., Shields, J., Gale, M.S., Hutto, E., Roberts, B.L., Siders, W.M., Kaplan, J.M.
Investigation of the Mechanism of Action of Alemtuzumab in A Human CD52 Transgenic Mouse Model
(2009) *Immunology*, 128 (2), pp. 260-270.
- Ramsköld, D., Parodis, I., Lakshmikanth, T., Sippl, N., Khademi, M., Chen, Y., Zickert, A., Malmström, V.
B Cell Alterations During BAFF Inhibition With Belimumab in SLE
(2019) *EBioMedicine*, 40, pp. 517-527.
- Ghazi, A., Trikha, A., Calhoun, W.J.
Benralizumab-A Humanized mAb to IL-5R α With Enhanced Antibody-Dependent Cell-Mediated Cytotoxicity-A Novel Approach for the Treatment of Asthma
(2012) *Expert opinion biological therapy*, 12 (1), pp. 113-118.
- Kuemmerle-Deschner, J.B., Haug, I.
Canakinumab in Patients With Cryopyrin-Associated Periodic Syndrome: An Update for Clinicians
(2013) *Therapeutic advances in musculoskeletal disease*, 5 (6), pp. 315-329.
- Curtis, J.R., Mariette, X., Gaujoux-Viala, C., Blauvelt, A., Kvien, T.K., Sandborn, W.J., Winthrop, K., Bykerk, V.P.
Long-Term Safety of Certolizumab Pegol in Rheumatoid Arthritis, Axial Spondyloarthritis, Psoriatic Arthritis, Psoriasis and Crohn's Disease: A Pooled Analysis of 11 317 Patients Across Clinical Trials
(2019) *RMD open*, 5 (1), p. e000942.
- Demirel Ögüt, N., Koç Yıldırım, S., Erbağcı, E., Hapa, F.A.
Ixekizumab Treatment in Patients With Moderate-To-Severe Plaque Psoriasis in A Real-World Clinical Setting
(2022) *Journal of cosmetic dermatology*, 21 (11), pp. 6215-6224.
- Gon, Y., Maruoka, S., Mizumura, K.
Omalizumab and IgE in the Control of Severe Allergic Asthma
(2022) *Frontiers in pharmacology*, 13, p. 839011.
- Walsh, G.M.
Profile of Reslizumab in Eosinophilic Disease and Its Potential in the Treatment of Poorly Controlled Eosinophilic Asthma
(2013) *Biologics*, 7, pp. 7-11.
- Kolbinger, F., Di Padova, F., Deodhar, A., Hawkes, J.E., Huppertz, C., Kuiper, T., McInnes, I.B., Bruin, G.
Secukinumab for the Treatment of Psoriasis, Psoriatic Arthritis, and Axial Spondyloarthritis: Physical and Pharmacological Properties Underlie the Observed Clinical Efficacy and Safety
(2022) *Pharmacology & therapeutics*, 229, p. 107925.
- Cherry, L.N., Yunker, N.S., Lambert, E.R., Vaughan, D., Lowe, D.K.
Vedolizumab: An $\alpha 4\beta 7$ Integrin Antagonist for Ulcerative Colitis and Crohn's Disease
(2015) *Therapeutic advances in chronic disease*, 6 (5), pp. 224-233.
- Ameri, A., Tavakoli-Far, B., Rostami, M., Abedi Kiasari, B., Sakhaei, D., Saad Ahmed, O., Forouzani, F., Fazli, Y.
Recent Advances in Atezolizumab-Based Programmed Death-Ligand 1 (PD-L1) Blockade Therapy for Breast Cancer
(2022) *International immunopharmacology*, 113, p. 109334.
(Pt A)

- Hegde, P.S., Jubb, A.M., Chen, D., Li, N.F., Meng, Y.G., Bernaards, C., Elliott, R., Chen, D.S.
Predictive Impact of Circulating Vascular Endothelial Growth Factor in Four Phase III Trials Evaluating Bevacizumab
(2013) *Clinical cancer research*, 19 (4), pp. 929-937.
- Raedler, L.A.
Darzalex (Daratumumab): First Anti-CD38 Monoclonal Antibody Approved for Patients with Relapsed Multiple Myeloma
(2016) *American health & drug benefits*, 9, pp. 70-73.
(Spec Feature), 27668047
- Ploessl, C., Pan, A., Maples, K.T., Lowe, D.K.
Dinutuximab: An Anti-GD2 Monoclonal Antibody for High-Risk Neuroblastoma
(2016) *Annals of pharmacotherapy*, 50 (5), pp. 416-422.
- Wang, Y., Sanchez, L., Siegel, D.S., Wang, M.L.
Elotuzumab for the Treatment of Multiple Myeloma
(2016) *Journal of hematology & oncology*, 9 (1), p. 55.
- Savoia, P., Astrua, C., Fava, P.
Ipilimumab (Anti-Ctla-4 Mab) in the Treatment of Metastatic Melanoma: Effectiveness and Toxicity Management
(2016) *Human Vaccines & Immunotherapeutics*, 12 (5), pp. 1092-1101.
- Thakur, M.K., Wozniak, A.J.
Spotlight on Necitumumab in the Treatment of Non-Small-Cell Lung Carcinoma
(2017) *Lung Cancer (Auckl)*, 8, pp. 13-19.
- Barth, M.J., Czuczman, M.S.
Ofatumumab: A Novel, Fully Human Anti-CD20 Monoclonal Antibody for the Treatment of Chronic Lymphocytic Leukemia
(2013) *Future oncology*, 9 (12), pp. 1829-1839.
- Burns, M.C., O'Donnell, A., Puzanov, I.
Pembrolizumab for the Treatment of Advanced Melanoma
(2016) *Expert opinion on orphan drugs*, 4 (8), pp. 867-873.
- Ross, J.S., Mulcahy, M.
HER2 Testing in Gastric/Gastroesophageal Junction Adenocarcinomas: Unique Features of a Familiar Test
(2011) *Gastrointestinal Cancer Research*, 4 (2), pp. 62-66.
- Navalkele, B.D., Chopra, T.
Bezlotoxumab: An Emerging Monoclonal Antibody Therapy for Prevention of Recurrent Clostridium difficile Infection
(2018) *Biologics*, 12, pp. 11-21.
- Emu, B., Fessel, J., Schrader, S., Kumar, P., Richmond, G., Win, S., Weinheimer, S., Lewis, S.
Phase 3 Study of Ibalizumab for Multidrug-Resistant HIV-1
(2018) *The new England journal of medicine*, 379 (7), pp. 645-654.
- Liu, X., Li, Y., Li, J., Zhou, J., Guo, J., Pu, Y., Jiang, Y., Li, X.
Comparing Recombinant Human Rabies Monoclonal Antibody (Ormutivimab) With Human Rabies Immunoglobulin (HRIG) for Postexposure Prophylaxis: A Phase III, Randomized, Double-blind, Non-inferiority Trial
(2023) *International journal of infectious diseases*, 134, pp. 53-62.
- Kummerfeldt, C.E.
Raxibacumab: Potential Role in the Treatment of Inhalational Anthrax

- (2014) *Infection and drug resistance*, 7, pp. 101-109.
- Bruno, V., Battaglia, G., Nicoletti, F.
The Advent of Monoclonal Antibodies in the Treatment of Chronic Autoimmune Diseases
(2011) *Neurological Sciences*, 31, pp. 283-288.
Suppl 3
 - Ellis, C.R., Azmat, C.E.
Adalimumab
(2023) *StatPearls*,
Treasure Island (FL): StatPearls Publishing LLC
 - Zahavi, D., Weiner, L.
Monoclonal Antibodies in Cancer Therapy
(2020) *Antibodies (Basel)*, 9 (3), p. 34.
 - Castelli, M.S., McGonigle, P., Hornby, P.J.
The Pharmacology and Therapeutic Applications of Monoclonal Antibodies
(2019) *Pharmacology research & perspect*, 7 (6), p. e00535.
 - Lee, J.Y., Lee, H.T., Shin, W., Chae, J., Choi, J., Kim, S.H., Lim, H., Heo, Y.-S.
Structural Basis of Checkpoint Blockade by Monoclonal Antibodies in Cancer Immunotherapy
(2016) *Nature communications*, 7 (1), p. 13354.
 - Rogovik, A.L., Carleton, B., Solimano, A., Goldman, R.D.
Palivizumab for the prevention of respiratory syncytial virus infection
(2010) *Canadian family physician*, 56 (8), pp. 769-772.
 - Aditya, S., Rattan, A.
Advances in CGRP Monoclonal Antibodies as Migraine Therapy: A Narrative Review
(2023) *Saudi journal of medicine & medical sciences*, 11 (1), pp. 11-18.
 - Li, M.
Enzyme Replacement Therapy: A Review and Its Role in Treating Lysosomal Storage Diseases
(2018) *Pediatric Annals*, 47 (5), pp. e191-e197.
 - Vachher, M., Sen, A., Kapila, R., Nigam, A.
Microbial Therapeutic Enzymes: A Promising Area of Biopharmaceuticals
(2021) *Current research in biotechnology*, 3, pp. 195-208.
 - Yari, M., Ghoshoon, M.B., Vakili, B., Ghasemi, Y.
Therapeutic Enzymes: Applications and Approaches to Pharmacological Improvement
(2017) *Current Pharmaceutical Biotechnology*, 18 (7), pp. 531-540.
 - Gurung, N., Ray, S., Bose, S., Rai, V.
A Broader View: Microbial Enzymes and Their Relevance in Industries, Medicine, and Beyond
(2013) *Biomed research international*, 2013, p. 329121.
 - Tiwari, M.
The Role of Serratiopeptidase in the Resolution of Inflammation
(2017) *Asian journal of pharmaceutical sciences*, 12 (3), pp. 209-215.
 - Jadhav, S.B., Shah, N., Rathi, A., Rathi, V., Rathi, A.
Serratiopeptidase: Insights into the Therapeutic Applications
(2020) *Biotechnol reports*, 28, p. e00544.

- Unlü, A.E., Takaç, S.
Improvement of Superoxide Dismutase Activity Using Experimental Design and Radical Promoters
Biotechnology & biotechnological equipment, 31 (5), pp. 1046-1054.
- Ghose, C., Euler, C.W.
Gram-Negative Bacterial Lysins
(2020) *Antibiotics (Basel)*, 9 (2), p. 74.
- Rodríguez-Cerrato, V., García, P., Huelves, L., García, E., Del Prado, G., Gracia, M., Ponte, C., Soriano, F.
Pneumococcal LytA Autolysin, A Potent Therapeutic Agent in Experimental Peritonitis-Sepsis Caused by Highly Beta-Lactam-Resistant Streptococcus pneumoniae
(2007) *Antimicrobial Agents and Chemotherapy*, 51 (9), pp. 3371-3373.
- Nawaz, N., Wen, S., Wang, F., Nawaz, S., Raza, J., Iftikhar, M., Usman, M.
Lysozyme and Its Application as Antibacterial Agent in Food Industry
(2022) *Molecules*, 27 (19), p. 6305.
- Gil-Montoya, J.A., Guardia-López, I., González-Moles, M.A.
Evaluation of the Clinical Efficacy of A Mouthwash And Oral Gel Containing the Antimicrobial Proteins Lactoperoxidase, Lysozyme and Lactoferrin in Elderly Patients with Dry Mouth – A Pilot Study
(2008) *Gerodontology*, 25 (1), pp. 3-9.
- Chen, Q., Li, W., Wang, J., Qu, X., Wang, G.
Lysozyme-Antimicrobial Peptide Fusion Protein Promotes the Diabetic Wound Size Reduction in Streptozotocin (STZ)-Induced Diabetic Rats
(2018) *Medical science monitor*, 24, pp. 8449-8458.
- Altaf, F., Wu, S., Kasim, V.
Role of Fibrinolytic Enzymes in Anti-Thrombosis Therapy
(2021) *Frontiers in Molecular Biosciences*, 8, p. 680397.
- Chen, H., McGowan, E.M., Ren, N., Lal, S., Nassif, N., Shad-Kaneez, F., Qu, X., Lin, Y.
Nattokinase: A Promising Alternative in Prevention and Treatment of Cardiovascular Diseases
(2018) *Biomark Insights*, 13, p. 1177271918785130.
- Kurosawa, Y., Nirengi, S., Homma, T., Esaki, K., Ohta, M., Clark, J.F., Hamaoka, T.
A Single-Dose of Oral Nattokinase Potentiates Thrombolysis and Anti-Coagulation Profiles
(2015) *Scientific reports*, 5 (1), p. 11601.
- Ghattas, M., Dwivedi, G., Lavertu, M., Alameh, M.G.
Vaccine Technologies and Platforms for Infectious Diseases: Current Progress, Challenges, and Opportunities
(2021) *Vaccines (Basel)*, 9 (12), p. 1490.
- Kayser, V., Ramzan, I.
Vaccines and Vaccination: History and Emerging Issues
(2021) *Human vaccines & immunotherapeutics*, 17 (12), pp. 5255-5268.
- Saxena, M., van der Burg, S.H., Melief, C.J.M., Bhardwaj, N.
Therapeutic Cancer Vaccines
(2021) *Nature reviews cancer*, 21 (6), pp. 360-378.
- Aldossary, A.M., Ekweremadu, C.S.M., Offe, I.M., Alfassam, H.A., Han, S., Onyali, V.C., Ozoude, C.H., Tawfil, E.A.
A Guide to Oral Vaccination: Highlighting Electro spraying as A Promising

- Manufacturing Technique Toward a Successful Oral Vaccine Development**
(2022) *Saudi pharmaceutical journal*, 30 (6), pp. 655-668.
- Nooraei, S., Bahrulolum, H., Hoseini, Z.S., Katalani, C., Hajizade, A., Easton, A.J., Ahmadian, G.
Virus-Like Particles: Preparation, Immunogenicity and Their Roles as Nanovaccines and Drug Nanocarriers
(2021) *Journal of nanobiotechnology*, 19 (1), p. 59.
 - Milligan, R., Paul, M., Richardson, M., Neuberger, A.
Vaccines for Preventing Typhoid Fever
(2018) *Cochrane database of systematic reviews*, 5 (5), p. Cd001261.
 - Clark, S.A., Borrow, R.
Herd Protection against Meningococcal Disease through Vaccination
(2020) *Microorganisms*, 8 (11), p. 1675.
 - Daniels, C.C., Rogers, P.D., Shelton, C.M.
A Review of Pneumococcal Vaccines: Current Polysaccharide Vaccine Recommendations and Future Protein Antigens
(2016) *The journal of pediatric pharmacology and therapeutics*, 21 (1), pp. 27-35.
 - Wang, S., Liang, B., Wang, W., Li, L., Feng, N., Zhao, Y., Wang, T., Xia, Z.
Viral Vectored Vaccines: Design, Development, Preventive and Therapeutic Applications in Human Diseases
(2023) *Signal transduction and targeted therapy*, 8 (1), p. 149.
 - Silveira, M.M., Moreira, G.M.S.G., Mendonça, M.
DNA Vaccines Against COVID-19: Perspectives and Challenges
(2021) *Life sciences*, 267, p. 118919.
 - Hoang, D.M., Pham, P.T., Bach, T.Q., Ngo, A.T.L., Nguyen, Q.T., Phan, T.T.K., Nguyen, G.H., Nguyen, L.T.
Stem Cell-Based Therapy for Human Diseases
(2022) *Signal transduction and targeted therapy*, 7 (1), p. 272.
 - Cabral, J.M.S., da Silva, C.L., Diogo, M.M.
Stem Cell Bioprocessing and Manufacturing
(2020) *Bioengineering (Basel)*, 7 (3), p. 84.
 - Jin, Y., Li, S., Yu, Q., Chen, T., Liu, D.
Application of Stem Cells in Regeneration Medicine
(2020) *MedComm*, 4 (4), p. e291.
 - Wang, J., Sun, M., Liu, W., Li, Y., Li, M.
Stem Cell-Based Therapies for Liver Diseases: An Overview and Update
(2019) *Tissue engineering and regenerative medicine*, 16 (2), pp. 107-118.
 - Li, L., Ngo, H.T.T., Hwang, E., Wei, X., Liu, Y., Liu, J., Yi, T.-H.
Conditioned Medium from Human Adipose-Derived Mesenchymal Stem Cell Culture Prevents UVB-Induced Skin Aging in Human Keratinocytes and Dermal Fibroblasts
(2019) *International journal of molecular sciences*, 21 (1), p. 49.
 - Rezaei, M., Zarkesh-Esfahani, S.H.
Optimization of Production of Recombinant Human Growth Hormone in Escherichia coli
(2012) *Journal of research in medical sciences*, 17 (7), pp. 681-685.
PMC3685787
 - Gilpin, D.A., Barrow, R.E., Rutan, R.L., Broemeling, L., Herndon, D.N.
Recombinant Human Growth Hormone Accelerates Wound Healing in Children With

Large Cutaneous Burns

(1994) *Annals of surgery*, 220 (1), pp. 19-24.

- Rigi, G., Rostami, A., Ghomi, H., Ahmadian, G., Mirbagheri, V.S., Jeiranikhameneh, M., Vahed, M., Rahimi, S.
Optimization of Expression, Purification and Secretion of Functional Recombinant Human Growth Hormone in Escherichia coli Using Modified Staphylococcal Protein A Signal Peptide
(2021) *BMC biotechnology*, 21 (1), p. 51.
- Annerén, G., Tuvemo, T., Carlsson-Skwirut, C., Lönnerholm, T., Bang, P., Sara, V.R., Gustafsson, J.
Growth Hormone Treatment in Young Children With Down's Syndrome: Effects on Growth and Psychomotor Development
(1999) *Archives of disease in childhood*, 80 (4), pp. 334-338.
- Frokjaer, S., Otzen, D.E.
Protein Drug Stability: A Formulation Challenge
(2015) *Nature reviews drug discovery*, 4 (4), pp. 298-306.
- Lipiäinen, T., Peltoniemi, M., Sarkhel, S., Yrjönen, T., Vuorela, H., Urtti, A., Juppo, A.
Formulation and Stability of Cytokine Therapeutics
(2015) *Journal of pharmaceutical sciences*, 104 (2), pp. 307-326.
- Murer, P., Neri, D.
Antibody-Cytokine Fusion Proteins: A Novel Class of Biopharmaceuticals for the Therapy of Cancer and of Chronic Inflammation
(2019) *New biotechnology*, 52, pp. 42-53.
- Arenas-Ramirez, N., Woytschak, J., Boyman, O.
Interleukin-2: Biology, Design and Application
(2015) *Trends in immunology*, 36 (12), pp. 763-777.
- Wang, X., Lin, Y.
Tumor Necrosis Factor and Cancer, Buddies or Foes?
(2008) *Acta pharmacologica sinica*, 29 (11), pp. 1275-1288.
- Trinchieri, G.
Interleukin-12 and the Regulation of Innate Resistance and Adaptive Immunity
(2003) *Nature reviews immunology*, 3 (2), pp. 133-146.
- Kak, G., Raza, M., Tiwari, B.K.
Interferon-Gamma (IFN- γ): Exploring Its Implications in Infectious Diseases
(2018) *Biomolecular concepts*, 9 (1), pp. 64-79.
- Shaldzhyan, A., Zabrodskaya, Y., Yolshin, N., Kudling, T., Lozhkov, A., Plotnikova, M., Ramsay, E., Vasin, A.
Clean and Folded: Production of Active, High Quality Recombinant Human Interferon- λ 1
(2021) *Process biochemistry*, 111, pp. 32-39.
- Hermant, P., Michiels, T.
Interferon- λ in the Context of Viral Infections: Production, Response and Therapeutic Implications
(2014) *Journal of innate immunity*, 6 (5), pp. 563-574.
- Ido, A., Numata, M., Kodama, M., Tsubouchi, H.
Mucosal Repair and Growth Factors: Recombinant Human Hepatocyte Growth Factor as An Innovative Therapy for Inflammatory Bowel Disease
(2005) *Journal of gastroenterology*, 40 (10), pp. 925-931.

- Henry, T.D., Rocha-Singh, K., Isner, J.M., Kereiakes, D.J., Giordano, F.J., Simons, M., Losordo, D.W., McCluskey, E.R.
Intracoronary Administration of Recombinant Human Vascular Endothelial Growth Factor to Patients With Coronary Artery Disease
(2001) *American heart journal*, 142 (5), pp. 872-880.
- Simons, M., Annex, B.H., Laham, R.J., Kleiman, N., Henry, T., Dauerman, Udelson, J.E., Chronos, N.A.
Pharmacological Treatment of Coronary Artery Disease With Recombinant Fibroblast Growth Factor-2
(2002) *Circulation*, 105 (7), pp. 788-793.
- Ivan, D.C., Berve, K.C., Walthert, S., Monaco, G., Borst, K., Bouillet, E., Ferreira, F., Locatelli, G.
Insulin-Like Growth Factor-1 Receptor Controls the Function of CNS-Resident Macrophages and Their Contribution to Neuroinflammation
(2023) *Acta neuropathologica communications*, 11 (1), p. 35.
- Yamakawa, S, Hayashida, K.
Advances in Surgical Applications of Growth Factors for Wound Healing
(2019) *Burns & trauma*, 7 (1), p. 10.
- Park, J.W., Hwang, S.R., Yoon, I.S.
Advanced Growth Factor Delivery Systems in Wound Management and Skin Regeneration
(2017) *Molecules*, 22 (8), p. 1259.
- Ingle, R.G., Fang, W.J.
An Overview of the Stability and Delivery Challenges of Commercial Nucleic Acid Therapeutics
(2023) *Pharmaceutics*, 15 (4), p. 1158.
- Baker, D.E., Demaris, K.
Defibrotide
(2016) *Hospital pharmacy*, 51 (10), pp. 847-854.
- Chambergo-Michilot, D., Alur, A., Kulkarni, S., Agarwala, A.
Mipomersen in Familial Hypercholesterolemia: An Update on Health-Related Quality of Life and Patient-Reported Outcomes
Vascular health and risk management, 18, pp. 73-80.
- Viores, S.A.
Pegaptanib in the treatment of wet, age-related macular degeneration
(2006) *International journal of nanomedicine*, 1 (3), pp. 263-268.
17717967
- Wilton-Clark, H., Yokota, T.
Casimersen for Duchenne Muscular Dystrophy
(2021) *Drugs today (Barc)*, 57 (12), pp. 707-717.
- Robinson, C., Pham, C., Zamarripa, A.M., Dugay, C.S., Lee, C.A., Berger, A.A., Landman, A., Ganti, L.
Intersen to Treat Polyneuropathy Associated with Hereditary Transthyretin (hATTR) Amyloidosis
(2022) *Health psychology research*, 10 (5), p. 67910.
- Errico, F., Marino, C., Grimaldi, M., Nuzzo, T., Bassareo, V., Valsecchi, V., Panicucci, C., Usiello, A.
Nusinersen Induces Disease-Severity-Specific Neurometabolic Effects in Spinal Muscular Atrophy
(2022) *Biomolecules*, 12 (10), p. 1431.

- Witztum, J.L., Gaudet, D., Freedman, S.D., Alexander, V.J., Digenio, A., Williams, K.R., Yang, Q., Bruckert, E.
Volanesorsen and Triglyceride Levels in Familial Chylomicronemia Syndrome
(2019) *The new England journal of medicine*, 381 (6), pp. 531-542.
- Yasuda, M., Keel, S., Balwani, M.
RNA Interference Therapy in Acute Hepatic Porphyrias
(2023) *Blood*, 142 (19), pp. 1589-1599.
- Cupido, A.J., Kastelein, J.J.P.
Inclisiran for the Treatment of Hypercholesterolaemia: Implications and Unanswered Questions from the ORION Trials
(2020) *Cardiovascular research*, 116 (11), pp. e136-e139.
- Scott, L.J., Keam, S.J.
Lumasiran: First Approval
(2021) *Drugs*, 81 (2), pp. 277-282.
- Adams, D., Tournev, I.L., Taylor, M.S., Coelho, T., Planté-Bordeneuve, V., Berk, J.L., González-Duarte, A., Polydefkis, M.
Efficacy and Safety of Vutrisiran for Patients With Hereditary Transthyretin-Mediated Amyloidosis With Polyneuropathy: A Randomized Clinical Trial
Amyloid, 30 (1), pp. 1-9.
- Weng, Y., Li, C., Yang, T., Hu, B., Zhang, M., Guo, S., Xiao, H., Huang, Y.
The Challenge and Prospect of mRNA Therapeutics Landscape
(2020) *Biotechnology advances*, 40, p. 107534.
- Yang, Y., Qin, Z., Zeng, W., Yang, T., Cao, Y., Mei, C., Kuang, Y.
Toxicity Assessment of Nanoparticles in Various Systems and Organs
(2016) *Nanotechnology reviews*, 6 (3), pp. 279-289.
- Thi, T.T.H., Suys, E.J.A., Lee, J.S., Nguyen, D.H., Park, K.D., Truong, N.P.
Lipid-Based Nanoparticles in the Clinic and Clinical Trials: From Cancer Nanomedicine to COVID-19 Vaccines
Vaccines (Basel), 9 (4), p. 359.
- Wang, J., Zhang, Y., Lu, Q., Xing, D., Zhang, R.
Exploring Carbohydrates for Therapeutics: A Review on Future Directions
(2021) *Frontiers in pharmacology*, 12, p. 756724.
- Tovar, A.M.F., Santos, G.R.C., Capillé, N.V., Piquet, A.A., Glauser, B.F., Pereira, M.S., Vilanova, E., Mourão, P.A.S.
Structural and Haemostatic Features of Pharmaceutical Heparins from Different Animal Sources: Challenges to Define Thresholds Separating Distinct Drugs
(2016) *Scientific reports*, 6 (1), p. 35619.
- Bae, S.H., Kim, M.R.
Subtype Classification of Functional Constipation in Children: Polyethylene Glycol Versus Lactulose
(2020) *Pediatrics international*, 62 (7), pp. 816-819.
- Ben-Haim, S., Ell, P.
18F-FDG PET and PET/CT in the Evaluation of Cancer Treatment Response
(2009) *Journal of nuclear medicine*, 50 (1), pp. 88-99.
- Bensinger, S.J., Christofk, H.R.
New Aspects of the Warburg Effect in Cancer Cell Biology
(2012) *Seminars in cell & developmental biology*, 23 (4), pp. 352-361.

- Lenci, E., Trabocchi, A.
Peptidomimetic Toolbox for Drug Discovery
(2020) *Chemical society reviews*, 49 (11), pp. 3262-3277.
- Mettu, R., Chen, C.-Y., Wu, C.-Y.
Synthetic Carbohydrate-Based Vaccines: Challenges and Opportunities
(2020) *Journal of biomedical science*, 27 (1), p. 9.
- Delorme, V., Lichon, L., Mahindad, H., Hunger, S., Laroui, N., Daurat, M., Godefroy, A., Berghe, H.V.D.
Reverse Poly(ϵ -caprolactone)-g-dextran Graft Copolymers. Nano-Carriers for Intracellular Uptake of Anticancer Drugs
(2020) *Carbohydrate polymers*, 232, p. 115764.
- Yang, O., Qadan, M., Ierapetritou, M.
Economic Analysis of Batch and Continuous Biopharmaceutical Antibody Production: A Review
(2019) *Journal of pharmaceutical innovation*, 14, pp. 1-19.
- Van Norman, G.A.
Limitations of Animal Studies for Predicting Toxicity in Clinical Trials: Is it Time to Rethink Our Current Approach?
(2019) *JACC: basic to translational science*, 4 (7), pp. 845-854.

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