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Production and Application of Monoclonal Antibodies: Review

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ABSTRACT

Monoclonal antibodies (MAbs), also called immunoglobulins, present substantial merits in biotechnology, immunology, and biochemistry. They are typically referred to as murine antibodies due to their origin in mice. Compared with polyclonal antibodies, the sophisticated production of MAbs render them more practical and therefore expensive. In the groundbreaking hybridoma technology discovered by Georges Kohler and Cesar Milstein, mice are immunized and then plasma cells are obtained from the spleen and merged with myeloma cells (cancer cells) to yield hybridoma cells. During mouse vaccination, prudent awareness is paid to animal welfare. MAbs have become instrumental in diagnosing livestock diseases after being incorporated into diagnostic procedures (immunohistochemistry, Immunofluorescence test, ELISA, and immunoblotting). The detection of microbial antigens or antibodies in diagnostic tests greatly relies on MAbs.
At the forefront of medical progress towards a new era of personalized therapy lies the utilization of MAbs to treat a wide spectrum of illnesses. With the birth of the first clinically certified MAb in 1975, the MAb market has undergone a surge in growth, now boasting an assessment in the billions. The continual development of MAbs confirms their permanent role within the treatment landscape, supported by their unique features. MAbs offer promising possibilities for addressing an expansive spectrum of ailments, varying from viral infections and septicemia to poisoning, asthma, autoimmune diseases, cancer, drug addiction, and beyond. The market for therapeutic antibody therapies has encountered a surge, pushed by the approval of new medicines to treat diseases that infect humans.

Introduction:

The immune system is a critical line of defense against a wide range of microbial pathogens responsible for causing numerous illnesses. Its various components work together to identify and eliminate these harmful agents, thereby maintaining the body's overall health and well-being. Its two main elements are humoral (antibody-mediated) and cellular (cell-mediated) immune responses. The humoral immune system comprises B lymphocytes, which detect foreign antigens and generate certain antibodies against them. Particularity and capability to supply long-term resistance to a certain antigen. Antibodies possess two fundamental properties that are vital for their function. Researchers leverage these unique characteristics to safeguard human health against various diseases.[1].

Antibodies, likewise known as immunoglobulins, are large, Y-shaped proteins primarily produced by plasma cells. Each tip of the "Y" of an antibody comprises a paratope specific for one particular epitope on an antigen, which the antibody recognizes via Fab's variable region [2] to identify a unique molecule of the pathogen termed as an antigen. Antibodies are classified based on affinity. Monoclonal antibodies (MAbs) are produced by identical immune cells, whole clones of a distinctive parent cell. Polyclonal antibodies bond to multiple epitopes, and MAbs can only have monovalent affinity, linking to the same epitope [3].

MAbs are generated via a traditional immunological method, boasting important utility in various domains such as biotechnology, biochemistry, and immunology. Operating as a defensive mechanism, antibodies can identify and neutralize invading agents such as viruses and bacteria. Antigen-binding sites, each

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with a paratope (similar to a lock) located at the upper ends of the "Y"-shaped antibody molecules, can detect a certain antigen unique to its target. In particular, a paratope binds to one epitope on a unique antigen (similar to a key), allowing these frames to link adequately. An antibody can tag either a microbe or an infected cell, thereby permitting other immune system components to target it and instantly suppress its goal [4].

Antibodies are vital to the immune response as they bind to soluble toxins, neutralizing their effects, and target pathogenic antigens on cell surfaces, preventing infection or marking them for destruction. Immune cells then eliminate pathogens through two complementary processes,antibody-dependent cellular cytotoxicity (ADCC) and antibody-dependent cellular phagocytosis (ADCP). The target particularity of antibodies is imparted by an antigen-binding fragment (Fab), and their biological activity is guided by a crystallizable component (Fc) (5). The specificity, persistence, and result of the antibody-dependent response are influenced by changes in the Fab and Fc sections. Georges Kohler and Cesar Milstein [5] developed the hybridoma technology for MAb production. In hybridoma production, a mixture of antigens can be utilized to generate certain antibodies, comprising one unique merit of this technique [6]. It also allows the selection of preferred antibodies from a purified antigen-derived mixture of antibody populations, with the possibility to isolate single-cell clones [7]. In immunodiagnostic procedures, MABs serve as reagents for determining the antigens of causative agents that directly or indirectly detect antibodies against the causative agents in serological assays [8]. They have also been employed for practical use, such as in the molecular detection of antigenic epitopes and development of monoclonal anti-idiotype antibodies for vaccine production to stimulate protective immunity. Since then, multiple MAbs have been forged for diagnostic procedures and immunotherapy applications [9].

After the discovery of heterologous MAbs for therapeutic usage, a great deal of research has been launched to develop several antibodies suitable for human use. The important achievement of creating MAbs in transgenic plants and animals cannot be understated. Glycoprotein-based MAbs are proficient in specifically binding to an epitope on an antigen; their usage in therapy has significantly increased, with several compounds obtaining regulatory acceptance [9].

Investigative efforts and progress in MAb research represent an innovative methodology for targeting certain mutations and irregularities in protein structure and expression across different diseases and contexts. Humanized MAbs represent the most rapidly expanding category of biotechnology-derived substances experiencing clinical trials, owing to the substantial progress in genetic sequencing and the application of foundational medical research to clinical settings. The annual worth of the global antibody industry is calculated to be $20 billion. MAbs have received FDA permission for human application, targeting diverse conditions such as cancer, cardiovascular conditions, infectious diseases, inflammatory disorders, and transplantation [10].

MAb Sources

In general, the formulation of an mAb entails the sequential progression through these phases: (a) extraction of an antibody with the requested characteristics, (b) protein modification to improve its targeting characteristics, (c) cultivating producers with stable antibody production stability, and (d) improving parameters for mAb purification and producer cultivation [11].

Antiviral MAbs are commonly sourced from the blood of vaccinated or infected grantors or synthetic libraries, including variable immunoglobulin fragments [10].

When a host (whether human or animal) becomes infected with a pathogen, their immune system will produce an enormous quantity of antibodies targeting the most conceivable epitopes; these antibodies will ripen within the body, thereby ascending their specificity and affinity [11]. Antibodies from infected donors have successfully been isolated using memory B cells. Despite these advancements, failure to develop a vigorous immune response upon virus infection always requires seeking alternative donors, with the prospect of no suitable donors being available. Under this condition, intentional immunization is carried out on the donor with either the pathogen itself or its antigens. A secondary immune response can be evoked by booster

immunizations, leading to the production of antibodies with heightened affinity [11].

Despite the preference for immune libraries, the antibodies' naive repertoire is important for other purposes, such as obtaining antiviral MAbs, primarily due to the extensive variety of antibodies. As a consequence, it has become a global antibody source against any antigen, facilitating the detection of antibodies against antigens that do not trigger a robust immune response. Also, significant advantages can be obtained from synthetic antibody fragments through antibody libraries over natural antibody sources in terms of designing and selecting antibodies [12]. Antibody generation is facilitated by a specific technology, which stimulates the production of a diverse range of antibodies beyond the capacity of a host's immune system. This option, however, has a risk of generating antibodies that are unusable in vivo and harmful to the body. Despite these shortcomings, the MAbs acquired from artificial libraries show potential to overcome viruses and bacterial toxins [13].

Method of MAb Production

Selection and isolation procedure of an antibody, various factors, including the source, desired affinity level, intended applications, budget restrictions, and time, must be considered, and each method has its benefits and drawbacks.

Hybridoma

Köhler and Milstein developed the hybridoma technology in 1976 to generate the first MAbs [14]. With this technology, MAbs and hybridomas can be produced from specialized cells. The donor's spleen is used to isolate B lymphocytes with immortal myeloma cells by disrupting cell membranes, such as by using Sendai virus or polyethylene glycol. A selective medium, which contains live hybrid cells capable of unlimited proliferation (e.g., myeloma) and antibody creation (e.g., B lymphocytes), is then used to seed the cells in the laboratory [15]. Limiting dilution can be used to obtain individual clones. Positive variants are then selected from individual clones screened for specific antibody activity. A novel antiviral mAb, palivizumab, has been developed with hybridoma technology. With the use of mature B cells, this technology provides antibodies with natural H- and L-chain pairings in the body and has passed selection and affinity maturation (Figure 1) [16]. A high probability of in vivo activity is associated with antibodies of this type [16].

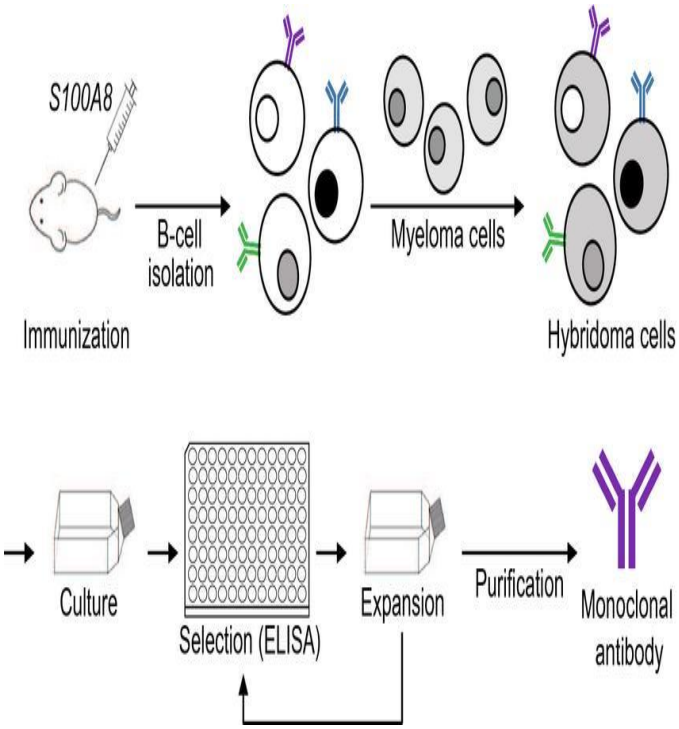

Figure 1: Schematic of monoclonal antibody generation with hybridoma technology [16].

Phage Display

In 1985, G.P. Smith initially suggested the idea of peptide phage display. The procedure involves acquiring a group of phages with filaments exhibiting the interested proteins merged with the P3 capsid protein. Target molecules are identified through the process of affinity selection, which utilizes specific ligands as revealed in Figure 2 [17].

Antibodies derived from phage presentation were first developed in the 1990s [18]. To generate phage libraries, researchers isolated mRNA from lymphocytes of donor and obtained cDNA fragments encoding various immunoglobulins (VH and VL regions) using reverse-transcriptase that helped inserting the mRNA into a phagemid vector. A vector consists of the phage protein pIII gene merged with the antibody fragments' nucleotide sequence, including a factor of antibiotic resistance, and the M13 phage genome's packaging site.. An infection with a helper phage, which is produced after the

phagemid library experiences transformation, is then established in *Escherichia coli* cells. Alongside a defective packaging signal, all phage proteins are encoded by the helper phage, which includes the entire M13 genome [19].

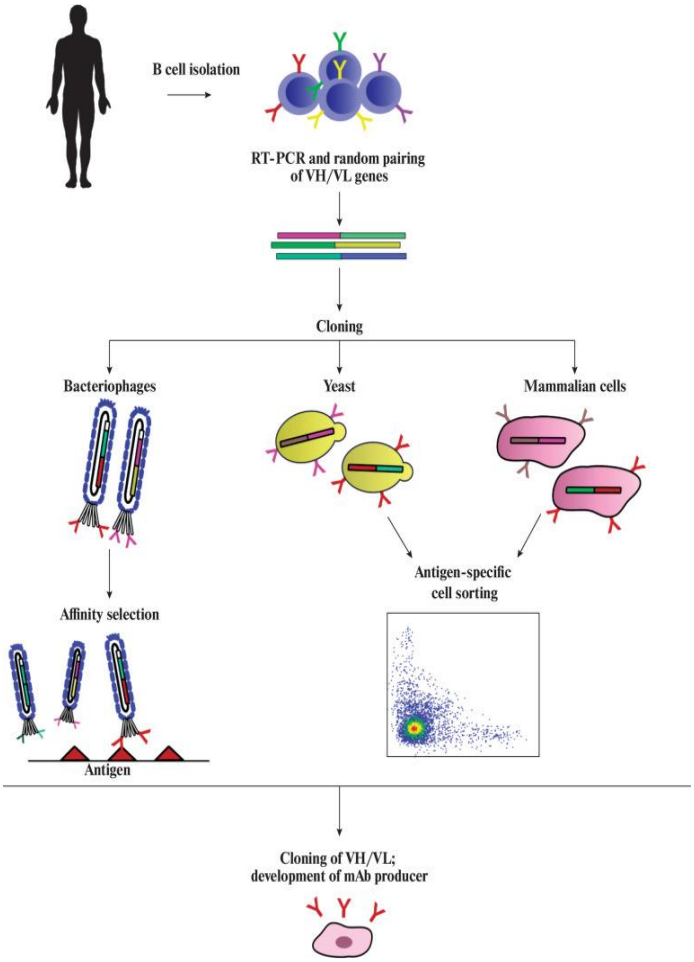

Figure 2: Schematic for approaches to produce monoclonal antibodies [17].

During the gathering of new particles, chimeric pIII and wild-type pIII vie for integration within the phage. This phenomenon gives a large collection of phagemid DNA, almost entirely full of phage particles carrying only one antibody fragment copy. The selection of affinity is then performed using target antigens, and the chosen variables of antibody fragments are reconstituted in full-size MAbs. Phage display has produced a variety of antiviral antibodies, which include M102.4, a vaccine that prevents and treats Nipah and Hendra viral infections; diridavumab, which targets influenza viruses; and foravirumab, a vaccine that prevents rabies infections [20]. Notable drawbacks associated with phage display include the difficulties inherent in the bacterial expression system, inappropriate antibody molecule folding, and deficiency of certain posttranslational alterations (such as glycosylation and disulfide bond formation) [21].

Yeast display

Yeast display, characterized by the manifestation of antibody fragments on the yeast cells' surface, ranks second in popularity among exhibition techniques. Different antibodies are obtained using mutagenesis protocols and precise cell sorting via flow cytometry.[22]. The eukaryotic alteration of secreted proteins following translation is the benefit of the yeast library. Yeast cell lines have evolved to guarantee the most accurate glycosylation of antibodies to date. Some viruses (such as phage λ), surface display on bacterial cells, and mRNA- and ribosome-based cell-free display methods can also be employed for the production of MAbs [23].

Single B-Cell VH-VL Gene Cloning

In 1996, a novel approach for the production of monoclonal antibodies (mAb) through the sorting of individual B cells was introduced, as illustrated in Figure 3.[24]. The separation of individual cells is typically conducted through FACS sorting [25]. This method involves the use of antigens tagged with a fluorescent dye. B cells that are specific to the target bind to these labeled proteins, allowing for their subsequent sorting. The immunoglobulin gene sequences for the heavy chain (VH) and light chain (VL) are extracted from the sorted individual B cells using reverse transcription PCR (RT-PCR), which leads to the creation of full-length monoclonal antibodies (MAbs). By employing single-cell RT-PCR, the unique VH-VL combinations are preserved, facilitating the efficient and rapid development of MAbs. [25].

Microdroplets and valve systems are different procedures used in this method (single-cell isolation) that involve microfluidic technologies. This approach has become popular due to its meticulous control, rapidity, cost-effective processing, and input materials [25].

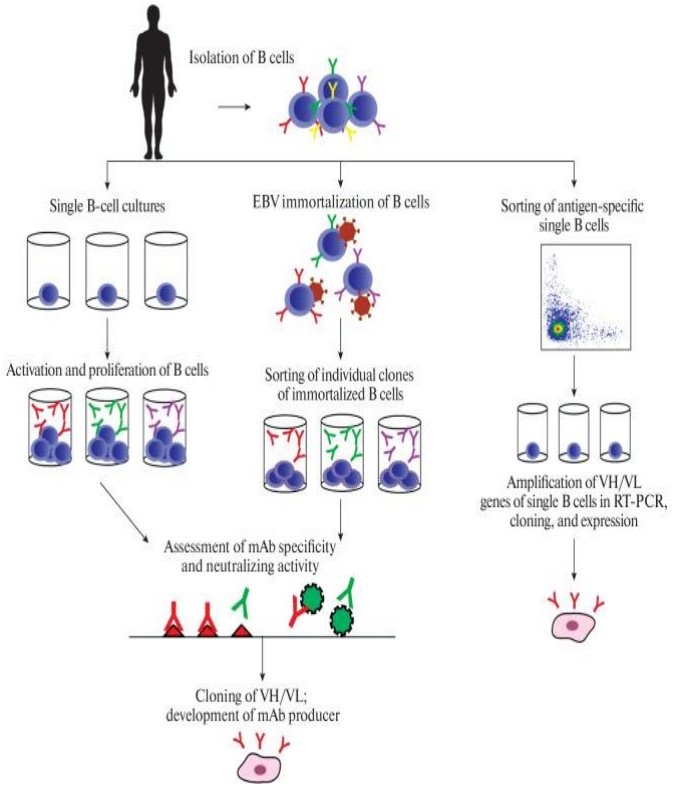

Figure 3: Monoclonal antibodies produced from B cells (memory cell): single B-cell culture, immortalization, and arrangement [24].

B-Cell Immortalization

Four decades have passed since the introduction of Epstein–Barr virus technology for immortalizing human B cells. For this method, the first step is to obtain memory B cells from donors showing an effective immune response. B cells are first exposed to the Epstein–Barr virus, leading to the generation of antibody-producing clones. The resulting culture fluid, which contains the secreted antibodies, is then analyzed for its specificity and ability to neutralize target pathogens. By employing direct functional screening, researchers can significantly shorten the time needed for the process while enhancing the chances of identifying antibodies with the desired properties. This method has successfully been used to isolate neutralizing antibodies against various viruses, including SARS-CoV and rabies. However, the wider application of this technique is limited by the risks posed by the oncogenic nature of the Epstein–Barr virus and the reduced productivity of the immortalized B cells.. Later progressions (such as employing a Toll-like receptor 9 agonist) have heightened the immortalized cell production to beyond 30%. With this technology, several remarkably potent and extensively neutralizing MAbs that are resistant to SARS-CoV, rabies virus, and other viruses have been procured [28].

Single B-Cell Cultures

B cells must first be immortalized to obtain functional B cell cultures. A substitute technique was developed to create sustained cultures of solitary primary B cells. The central idea of this approach revolves around positioning B cells onto the nutrient layer of cells harboring the primary receptor CD40L on their surface and then supplementing the nutrient medium with cytokines IL-21, IL-2, and IL-4. Under these circumstances, B lymphocytes are triggered and form an MAbs-producing cell culture. The subsequent step involves the direct functional inspection of the culture medium, followed by the extraction of nucleotide sequences of the VH-VL genes from the assigned clones using RT-PCR and the subsequent construction of MAbs [29]. Through this approach, neutralizing antibodies against H1N1, influenza, HIV-1, and dengue viruses have been isolated. A reduction in threats related to other methods is achieved through the straightforward analysis of antibodies from normal antibody-producing cells, which is the most important benefit of this B-cell-based method (for example, alterations in the antibody molecules' structure or loss of certain antibody variables owing to heterogeneous expression) [30]. However, this method has some defects, such as low expression of specific B cells in donor blood serum and low rate of survival. Efficiency is enhanced through the use of plasma cell cultures. These cells increase the possibility of detection of an antibody with specificity and high affinity and comprise at least 100 times more immunoglobulin mRNA, and produce antibodies at the endpoint of somatic hypermutagenesis, an antigen-dependent response. Increasing the efficiency of screening can be further performed by automating the process. Modern methods include computational techniques, high-throughput sequencing, and proteomics [31].

Extensive details about the multiplicity of the antibody repertoire, which is employed to detect certain MAbs (Figure 4) [13], are provided by high-throughput

sequencing methods. Owing to the reverse representation, B cell clones provide material for the formation of antibodies [13].

Researchers determined the most prevalent (VH-VL) amino acid sequences in plasma cells from vaccinated mice by conducting mass parallel sequencing of those genes. These sequences were then specified based on their proportional abundance, leading to the creation of antibody single-chain variable fragments, many of which display specificity toward the antigen. An independent study used overlapping RT-PCR to acquire VH-VL DNA fragments from individual B cells, followed by the sequencing of the most frequent variants [32]. Specific antibodies were successfully used to target Ebola virus glycoprotein using different antibody sequences [33].

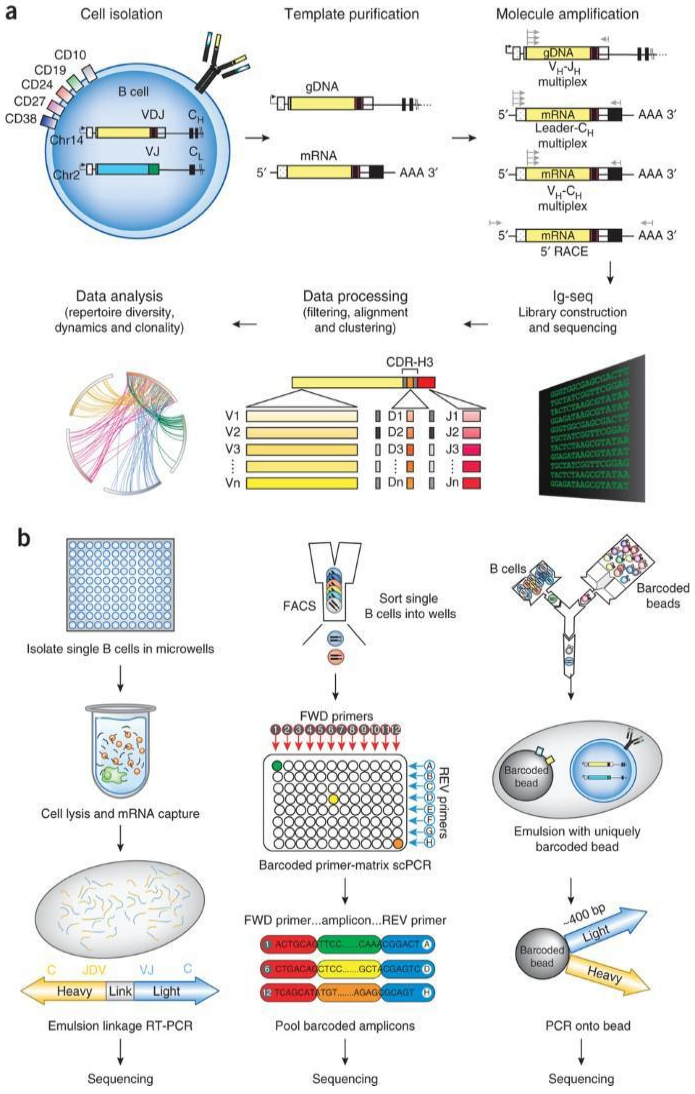

Figure 4: Monoclonal antibody creation via high-throughput sequencing and proteomics methods [13].

Specific MAbs from the donor's antibody repertoire can be identified by combining proteomics and genomics techniques. In this case, mass spectrometry results can be interpreted using the sequencing data as a reference or basis [34]. Moreover, sequencing outcomes are combined with bioinformatic data to detect antibodies. For example, the sequence of the 10E8 anti-HIV-1 antibody was used to construct evolutionary phylogenetic trees by employing nucleotide sequences from an HIV-positive donor's VH-VL repertoire. The relative genetic distance between wild type 10E8 and the selected strand pairing was calculated in silico [35]. Through this process, 11 functional MAbs similar to 10E8 and exhibiting neutralizing activity were isolated. From another HIV-positive donor's repertoire, many broadly neutralizing MAbs were isolated using this strategy [36].

Antibodies targeting the novel coronavirus SARS-CoV-2 were identified through the application of bioinformatics methodologies. Advanced computational models were constructed to investigate the interactions between the viral spike (S) protein and antibodies specifically derived from SARS-CoV, which possesses the most closely related antigenic profile to that of SARS-CoV-2. Based on the outcomes of these simulations, a SARS-CoV-specific antibody, referred to as CR3022, was identified for its potential to interact with the SARS-CoV-2 S protein. The specificity of this antibody's interaction must be rigorously validated through laboratory experimentation. [37].

Recent advances in computational methods have led to a reduction in time and cost for antibody detection and the tight control of parallel screening of many physicochemical properties. Ultimately, these methods will enable the development of antibodies with necessary de novo properties.

Therapeutic MAbs are regulated by the Food and Drug Administration (FDA) [38].

The Center for Biologics Evaluation and Research and Center for Drug Evaluation and Research regulate he application of MAbs and antibodies, which are

recognized as "biopharmaceuticals" by the FDA. As stated in the FDA's "Points to Consider" paper, guidance is offered for producers on issues to be considered during the development and inspection of MAbs for human utilization and the submission of data required by the Investigational New Drug or biologics licensing applications [39]. Following the transformation of antibody-producing cells with malignant morphologies into host cells, the agency recommends measures to preserve human health by addressing potential virus and cellular DNA incorporation. These measures, such as ensuring the immunoconjugates' purity and checking how well purification methods can remove adventitious agents, are needed to prevent the finished product from being contaminated by possible pathogens. Producers must exert efforts to prevent cultured cell contamination and follow wildlife safeguard guidelines [40].

As the main cure procedure for all sorts of illnesses within the last 30 years, therapeutic MAbs have become increasingly substantial. Owing to major technological advancements, MAb treatment research has sped up and become efficient during this period. By permitting 48 additional MAbs since 2008, the US FDA has contributed to an accumulative global market of 61 MAbs in therapeutic use by the end of 2017. Table 1 presents the list of therapeutic antibodies authorized by the FDA in the period of 2000–2010 [41]. According to numerous sources, which involve the antibody society, corporate pipelines, databases of therapeutic antibodies, and news announcements, 18 novel antibodies were approved by the US FDA in 2018–2019. In 2018, the FDA greenlit 12 new MAbs, comprising one-fifth of all medicines authorized. By 2024, 50% of these will reach blockbuster status, yielding minimum annual incomes of $1 billion [42].

Production and Purification of MAbs from Plant Systems

Metamorphosed plants cultivated in vitro serve as bioreactors and plant systems for large-scale monoclonal antibody (mAb) production. This approach enables the renewal of mature plants and the propagation of cells as part of a cell-suspension culture system. Plant systems, which include roots, leaves, and stems from mature plants that can grow and be transplanted into soil pots, contribute to the production of plant biomass in vitro.(43Plants are more adaptable for use in vitro and in vivo than the above cell-culture generation systems. [44]. The plant systems of alfalfa, tobacco, and some other species have been developed as the best and most accessible and familiar sources of leaf biomass. The seeds of maize and soybean can create and accumulate MAbs. All the soluble proteins in certain vegetable plants are relatively abundant, which could be fruitful for the expression of recombinant proteins [45].

Table 1: FDA-confirmed therapeutic antibodies for the period of 2000–2010 [41].

Name	Antibody	Target	Year	Indication
Campath	Alemtuzumab	CD5	2001	T-cell lymphoma, Chronic lymphatic leukemia
Zevalin	Ibritumomab tiuxetan	CD20	2002	CD20
Bexxar	Adalimumab	TNF-α	2002	autoimmune disorders such as MorbusChron, rheumatoidarthritis, psoriatic arthritis
Bexxar	Tositumomab	CD20	2003	Non-Hodgkin's lymphoma
Xolair	Omalizumab	IgE	2003	Severe (allergic) asthma
Avastin	Bevacizumab	VGEF	2004	metastatic breast cancer, Metastatic colorectal cancer, non-smallcell lung cancer,
Tysabri	Natalizumab	α4 subunit of a4β1	2004	Chron's disease, Multiple Sclerosis
Erbitux	Cetuximab	EGFR	2004	Neck cancer, colorectal and head cancer
Vectibix	Panitumumab	EGFR	2006	Metastatic colorectal carcinoma
Lucentis	Ranibizumab	VEGF-A	2006	Wet macular degeneration
Soliris	Eculizumab	CD59	2007	Paroxysmal nocturnal hemoglobinuria
Cimzia	Certolizumab pegol	TNF-α	2008	Rheumatoid arthritis, Crohn's disease
Simponi	Golimumab	TNF-α	2009	Psoriatic and rheumatoid arthritis, kylosing and active spondylitis

Chinese cabbage emerges among vegetable plants as having an elevated total soluble protein threshold in its leaf biomass, making it a promising bioreactor for synthesizing recombinant therapeutic proteins [46]. The major advantages of tobacco are elevated leaf biomass product and quick scale-up via seed generation, distinguishing it from other plant species. A modern paper emphasized the similarity in the level of expressed adapted proteins between tobacco stems and leaves, indicating that the entire tobacco plant biomass can be harnessed for creating modified therapeutic proteins, ultimately improving the efficiency of production costs upstream [43].

As a nonedible and non-livestock plant, tobacco has been vastly studied as an expression platform free from human pathogen pollution, thus mitigating biosafety apprehensions [47]. Nonetheless, it harbors nicotine or other harmful alkaloids that must be discarded through further extraction. Tobacco also produces antibodies with heterogeneous N-glycosylation owing to alterations in antibody localization along the secretory pathway, which might pose challenges in maintaining the produced antibodies' quality [48]. Alfalfa's advantages involve a considerable biomass yield and a uniform glycan structure [47]. However, is utilized in animal nutrition and as an origin of oxalic acid. *Arabidopsis* can be seen as a nonfeed plant expression system, featuring a heightened total soluble protein level in stems and leaves [44]. Despite maize boasting a superior biomass production, its in vitro transformation and treatment are daunting. In summary, leaves and seeds, both within the plant expression systems, show benefits and drawbacks, making them suitable for expressing all intended proteins. The active and complex metabolism of leaves provide it with an elevated protease activity that degrades specific proteins [48].

Antibodies purified from plants were obtained using protein A or G affinity chromatography [49]. Plant tissue homogenization is needed to destroy cell walls and dispose cell remains, harmful chemicals, and pollutants, which must be subsequently eradicated for purification [50]. Many miscellaneous fusion protein processes have been devised to ensure the production of high levels of recombinant proteins and effective purification in plants. The Zera domain can accumulate maize storage proteins rich in proline within the ER deposit in plant cells to form bodies of supramolecular aggregates of the polyproline structure. This sequence allows for the elevated accretion of recombinant proteins in the ER, facilitating protein restoration through simple centrifugation and homogenization and empowering effective purification [51].

Elastin-like polypeptides appear in a soluble form below their transition temperature and gather into micron-scale coacervates above this temperature [52]. A selective removal of soluble and insoluble pollutants can be accomplished without utilizing chromatography to purify recombinant proteins fused to polypeptide tags that look similar to elastin [53].

Hydrophobin, a surface-active fungal protein, enhances the accumulation of its fusion recombinant protein by creating protein bodies in plants. An aqueous two-phase system based on surfactants facilitates effective purification by altering the hydrophobicity. These protein fusion techniques could dramatically increase the accumulation of recombinant antibodies in a plant expression system while reducing the cost of purification [54].

Applications of MAbs in Cancer

Recent advancements in cancer treatment have made MAb therapy one of the most important routes. However, clinical relevance and mechanisms are still inadequately understood. Antibody therapy has had significant clinical successes, but the problem of therapeutic resistance remains. Research should concentrate on identifying new methods to increase clinical efficacy by analyzing the mechanisms of MAbs in the future [55].

ADCC was found to mediate mAb responses, so engineering strategies that boost ADCC activity could be popular in the future. Several promising avenues have been identified for maximizing the clinical benefits of mAb therapy when tumor-targeted MAbs are combined with ICB. Moreover, numerous biomarkers are related to mAb efficacy and resistance, including mutations in the antibody target and signaling pathways. Incorporating the inhibitors of these alternative signaling pathways in future mAb treatment strategies will be necessary to overcome resistance to them. Some patients with cancer

will be offered curative treatment using MAbs as the paradigm continues to evolve [55].

A recent trend in mAb-based strategies is to target immune cells rather than tumor antigens to improve the effectiveness of their antitumor activity. In the development of MAbs, bispecific T cell engager (BiTE) antibodies were used to stimulate anti-tumor immunity from T lymphocytes by targeting tumor antigens, such as Cluster of Differentiation 19 (CD19) and T cell activation receptor, CD3. Even when doses for BiTEs were three orders of magnitude lower than those for the parent mAb alone, the former were still able to induce tumor regression through the combination of direct targeting of the tumor cells and the recruitment of cytotoxic T cells into the tumor microenvironment [56].

The significant clinical benefits of CD19-CD3 BiTE blinatumomab were observed in a patient with lymphoblastic leukemia, and the drug was approved by the FDA in 2017 [57]. A clinical test is currently underway, testing the ability of BiTEs derived from the well-known MAbs trastuzumab and cetuximab, to treat cells with anti-human epidermal receptors (anti-HER2) and anti-epidermal growth factor receptor (anti-EGFR). Figure 5 [55] illustrates how different mAb techniques induce activating receptors such ICOS, CD40, CD27, OX40, and 4-1BB(CD137) to boost T cell-specific immunity against tumor cells. MAbs against OX40 and 4-1BB and agonist antibodies targeting CD40 trigger T cells and promote antigen displaying via dendritic cells while attenuating the function of inhibitory T regulatory cells (Tregs) [58]. While participating with other immunotherapy procedures or alone, MAbs conceived to boost activating receptors undergo numerous phases of clinical practices. Clinical tests of MAbs that target CD25 on inhibiting Tregs are also ongoing, including daclizumab, which targets CD25 on Tregs.

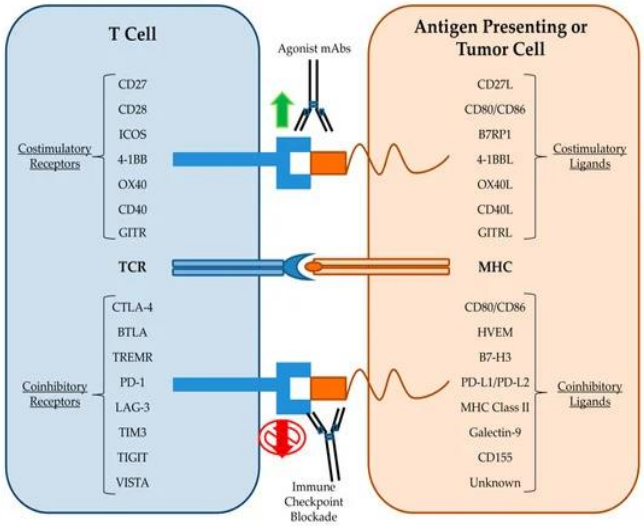

Figure 5: Immune checkpoint targets of monoclonal antibodies [55].

In addition to autoimmune diseases and infectious diseases, MAbs also are used for the treatment of tumors, metabolic disorders, and infectious diseases [40,59] (Figure 6) [39].

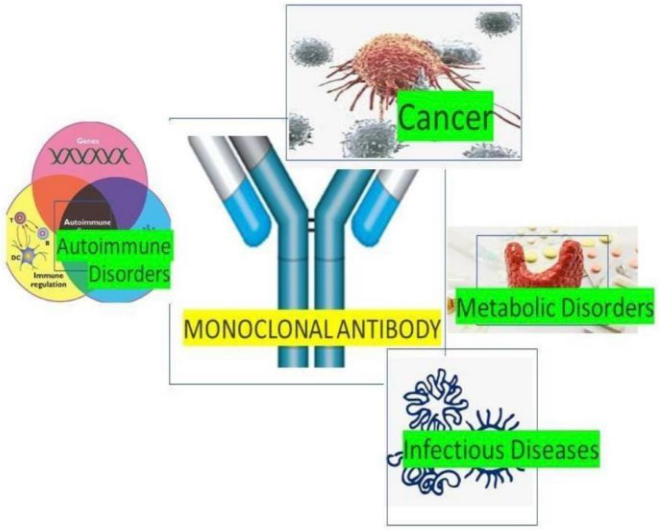

Figure 6: Other uses of MAbs for therapeutic purposes [39].

In Diagnostic Histopathology

MAbs are used in histopathology to classify tissues and organs depending on their representation of markers reflecting cellular or tissue development. The production of MAbs against antigens that are related to organs, such as α-fetoprotein, human chorionic gonadotrophin,

placental alkaline phosphatase, and prostate-specific antigen, assist in distinguishing primary tumors [60]. In addition to detecting undifferentiated metastases in tissues and organs, MAbs help distinguish morphologically similar lesions, such as pleural and peritoneal mesotheliomas and adenocarcinomas. Through the immunocytological analysis of bone marrow, other tissue aspirate, lymph nodes, and other tissues, certain MAbs can detect occult metastases at a higher sensitivity than standard histopathological staining [60,61].

Conclusions

MABs are produced by cloning one type of immune cell to create identical copies, allowing the targeted treatment of various diseases. These pharmaceutical APIs are developed using hybridoma or recombinant DNA technology. The hybridoma technology involves merging antibody-producing cells with immortalized cells to create hybrid cells that produce large amounts of monoclonal antibodies. Meanwhile, the recombinant DNA technology uses genetically modified organisms such as bacteria or mammalian cells to produce monoclonal antibodies.

References

[1] Poongodi. V, K. Saraswathi Gopal and Anitha Raghunathan .(2018). Monoclonal antibody an updated review in dentistry. *International Journal of Current Research*;Vol.10:72408-72412, DOI: 10.24941/ijcr.31949.08.2018.

[2] Hongtai Jing1, Zhengtao Gao1, Sheng Xu4, Tao Shen, Zhangzhi Peng, Shwai He, Tao You, Shuang Ye6, , Wei Lin1, Siqi Sun. (2024). Accurate prediction of antibody function and structure using bio-inspired antibody language model. *Briefings in Bioinformatics, 2024, 25(4), bbae245* 189-194, DOI: https://doi.org/10.1093/bib/bbae402

[3] Ahmed Elnaggar, Michael Heinzinger, Christian Dallago, Ghalia Rehawi, Yu Wang, Llion Jones, Tom Gibbs, Tamas Feher, Christoph Angerer, Martin Steinegger, Debsindhu Bhowmik, Burkhard Rost. (2021).Prottrans: toward understanding the language of life through self-supervised learning. IEEE Trans Pattern Anal Mach Intell;44(10):7112–27.

[4] Lin Zhaoa , Qi Wub , Ruirui Songc and Zhenyu Yun Genetic Engineering Antibody: Principles and Application. *IOP Conf. Series: Materials Science and Engineering 612*, doi:10.1088/1757-899X/612/2/022045

[5] Pecetta S, Finco O,Seubert .(2020(.AQuantum leap of monoclonal antibody (mAb) discovery and development in the COVID-19 era". *Seminars in Immunology journal* , 50:101427. DOI: 10.1016/j.smim.2020.101427

[6] Buss N. A. P. S,Henderson S. J, McFarlane M,ShentonJ. M, De Haan .(2012(LMonoclonal antibody therapeutics: History and future". *Current Opinion in Pharmacology* journal,Vol. 12(5): 615-622. DOI: 10.1016/j.coph.2012.08.001

[7] Chowdhury N, Sood N. K, Lal S, Gupta K, Singla .(2013(.L. DDevelopment of some larval nematodes in experimental and natural animal hosts: An insight into development of pathological lesions vis-a-vis host-parasite interactions. *The Scientific World Journal*, 8 pages. DOI: 10.1155/2013/162538

[8] Deb R, Chakraborty S, Veeregowda B, Verma A. K, Tiwari .(2013(.RMonoclonal antibody and its use in the diagnosis of livestock diseases. *Special Issue in Antibody Research*,Vol. 4(4A): 50-62. DOI**:** 10.4236/abb.2013.44A008

[9] Santos-Neto J. F, Oliveira F. O, .Hodel K V. S,Fonseca L. M. S, Badaro R, Machado B. A. S. .(2021)Technological Advancements in Monoclonal Antibodies. *The Scientific World Journal*, DOI: 10.1155/2021/6663708

[10] Pendley C, Schantz A, Wagner C. .(2003)Immunogenicity of therapeutic monoclonal antibodies. *Current Opinion in Molecular Therapeutics*. 2003,Vol.5:172–179.

[11] Chan S. K, Rahumatullah A, Lai J. Y, .Lim T S. .(2017)Naïve Human Antibody Libraries for Infectious Diseases Adv. Exp. Med. Biol J. 2017; DOI: 10.1007/978-3-319-72077-7_3

[12] Wu Y ,Li S, Du L , Wang C , Zou P,B Hong B, Yuan M, Ren X, Tai W, Kong Y, Zhou C, Lu L,Zhou X ,Jiang S , Ying T .(.2017) .Neutralization of Zika

virus by germline-like human monoclonal antibodies targeting cryptic epitopes on envelope domain .IIIE *merging and Microbes Infections journal*,Vol. 6:e89. DOI: 10.1038/emi.2015.74

[13] Giuseppe P, Bruno C, Craig F, Victor S. Joo, and Laurent P.(2022). Antibodies to combat viral infections: development strategies and progress. Nat Rev Drug Discov. 21(9): 676–696. doi: 10.1038/s41573-022-00495-3

[14] Köhler G and Milstein C .(1975).Continuous cultures of fused cells secreting antibody of predefined specificity,*Nature*, 256:495–497,DOI: 10.1038/256495a0

[15] Pollack P and Groothuis J.R. .(2002).Development and use of palivizumab (Synagis): a passive immunoprophylactic agent for RSV" , *Journal of infection and Chemotherapy*,2002,ol.8:201–206. DOI: 10.1007/s10156-002-0178-6

[16] Jong-Pyo K., Hanool Y., Eun-Jung K., Yun-Gon K., Chang-Soo.L, Byoung J., Byung-Gee K.,J Hee-Jin J.(2003). Generation of a novel monoclonal antibody against inflammatory biomarker S100A8 using hybridoma technology. 45(Suppl 1):1-12, DOI:10.1007/s10529-023-03364-0

[17] Smith GP. (1985).Filamentous fusion phage: novel expression vectors that display cloned antigens on the virion surface",*Science j* , 228:13151317. DOI: 10.1126/science.4001944

[18] McCafferty J , Griffiths AD , Winter G, Chiswell DJ. (1990).Phage antibodies: filamentous phage displaying antibody variable domains" *Nature*. Vol.348:552–554. DOI: 10.1038/348552a0

[19] Ledsgaard L , Kilstrup M , Karatt-Vellatt A, McCafferty J ,LaustsenA.H .(2018).Basics of Antibody Phage Display Technology *Toxins(Basel)J*.Vol.10:236. DOI: 10.3390/toxins10060236

[20] Frenzel A., Schirrmann T., Hus M .(2016).Phage display-derived human antibodies in clinical development and therapy *MAbs*.,Vol.8:1177–1194, DOI: 10.1080/19420862.2016.1212149

[21] Sandhya B, Shanshan L, Michael S, Hillary A V, Xueyong Z, Nurgun K, Robin B, Jessica A F, Stephen J K, Pavlo G, Iuliia G, Hannah L T, Adolfo G, Sheng L, Andrew B W, Ian A W, James E C.(2019) A Site of Vulnerability on the Influenza Virus Hemagglutinin Head Domain Trimer Interface. *Cell. 2019 May 16;177(5):1136-1152.e18*. DOI: 10.1016/j.cell.2019.04.011

[22] Sun Y., Ban B., Bradbury A., Ansari G.A., Blake D.A. (2016).Anal. Combining Yeast Display and Competitive FACS to Select Rare Hapten-Specific Clones from Recombinant Antibody Libraries *Analaytical Chemistry*, Vol.88:9181–9189. DOI: 10.1021/acs.analchem.6b02334

[23] Lipovsek D and Pluckthun AJ. (2004).In-vitro protein evolution by ribosome display and mRNA display..*Immunol Methods,* Vol.290:51–67. DOI: 10.1016/j.jim.2004.04.008

[24] Atsumi Sakaguchi, Yoichiro Tanaka, Eiki Shoji, Teppei Takeshima, Rina Sakamaki, Takao Matsuba & Yasuyuki Kurihara.(2023). Rapid, simple, and effective strategy to produce monoclonal antibodies targeting protein structures using hybridoma technology. *Journal of biological Engineering.* Vol.) 17:24 https://doi.org/10.1186/s13036-023-00345-9.

[25] Perry S.T , Keogh E, Morton M , Koudstaal W , Pascual G. (2019).Single-cell Screening Method for the Selection and Recovery of Antibodies with Desired Specificities from Enriched Human Memory B Cell Populations".*J Vix Exp*, Vol.22:(150). DOI: 10.3791/59809

[26] Guarner J, Hale GL (2019) Four human diseases with signifcant public health impact caused by mosquito-borne faviviruses: West Nile, Zika, dengue and yellow fever. Semin Diagn Pathol 36:170–176. https://doi.org/10.1053/j.semdp.2019.04.009

[27] González-Fernández Á, Bermúdez Silva FJ, López-Hoyos M, Cobaleda C, Montoliu L, Del Val M, Leech K.(2020). Non-animal-derived monoclonal antibodies are not ready to substitute current hybridoma technology. Nature Meth. 17:1069–70. https://doi.org/10.1038/s41592-020-00977-5.

[28] Corti D and Lanzavecchia A.. (2004).Broadly Neutralizing Antiviral Antibodies Annu. Rev. Immunol".*Nat Med J,* Vol.31:705–742. DOI: 10.1146/annurev-immunol-032712-095916

[29] Parray HA, 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. Int Immunopharmacol. 2020;85:106639. https://doi.org/10.1016/j.intimp.2020.106639.

[30] Mitra S, Tomar PC. Hybridoma technology; advancements, clinical significance, and future aspects. J Genet Eng Biotechnol. 2021;19:159. https://doi.org/10.1186/s43141-021-00264-6.

[31] Jin Lu I, Tadas P, Kim T, Jeroen A, Michael N, Jamie F, Michael R, Raymond W.S.(2014) IgG variable region and VH CDR3 diversity in unimmunized mice analyzed by massively parallel sequencing. *Mol Immunol*. Vol.57(2):274-83. DOI: 10.1016/j.molimm.2013.09.008

[32] Reddy S.T., Ge X., Miklos E., Hughes R.A. Hyun S, Kang H., Chrysostomou C., Hunicke S.P-., verson B.L., Tucker P.W., Ellington A.D., and Georgiou G.(2010).Monoclonal antibodies isolated without screening by analyzing the variable-gene repertoire of plasma cells *Nat. Biotechnol*Vol.28:965–969 DOI: 10.1038/nbt.1673

[33] Wang B., Kluwe C.A., Lungu O.L., DeKosky B.J., Kerr S.A., Johnson E.L., Tanno H., Lee C.H., Jung J., Rezigh A.B., Carroll S.M., Reyes A.N., Bentz J.R., Villanueva I., Altman A.L., Davey R..,A.,Ellington. D, Georgiou G. (2015).Facile Discovery of a Diverse Panel of Anti-Ebola Virus Antibodies by Immune Repertoire Mining". *Sci. Rep*. Vol. 5:13926. DOI: 10.1038/srep13926

[34] Parola. C, Neumeier D., Reddy S.T. (2018).Integrating high-throughput screening and sequencing for monoclonal antibody discovery and engineering.". *Immunology* . Vol.153:31–41. DOI: 10.1111/imm.12838

[35] Zhu. J, Ofek G., Yang Y., Zhang B., Louder M.K., Lu G., McKee K., Pancera. M, Skinner J., Zhang Z., Parks R., Eudailey J., Lloyd K.E., Blinn J., Alam S.M., Haynes B.F., Simek M., Burton D.R., Koff W.C. NISC Comparative Sequencing Program, Mullikin J.C,. Mascola J.R, Shapiro L., and Kwong P.D . (2013).Mining the antibodyome for HIV-1–neutralizing antibodies with next-generation sequencing and phylogenetic pairing of heavy/light chains" .*Proc. Natl. Acad. Sci. U. S. A.* 2013;Vol.110:6470–6475. DOI: 10.1073/pnas.1219320110

[36] Jiang Z , Xueling W, Baoshan Z, Krisha M, Sijy O, Cinque S, Tongqing Z, Joseph P; NISC Comparative Sequencing Program; James C, Peter D.K, John R, Lawrence S. (2013).De novo identification of VRC01 class HIV-1-neutralizing antibodies by next-generation sequencing of B-cell transcripts Proc. *Natl. Acad. Sci. U. S. A.* Vol.110(43):E4088-97. DOI: 10.1073/pnas.1306262110

[37] Tian. X, Li. C, Huang A., Xia S., Lu S., Shi Z., Lu L., Jiang. S, Yang Z., Wu Y., Ying T. .(2020).Potent binding of 2019 novel coronavirus spike protein by a SARS coronavirus-specific human monoclonal antibody. *Emerg. Microbes Infect.* Vol.9:382–385.DOI: 10.1080/22221751.2020.1729069

[38] Sormanni P., Aprile F., Vendruscolo M. (2018).Third generation antibody discovery methods: in silico rational design.*Chem. Soc. Rev*..Vol. 47:9137–9157. DOI: 10.1039/c8cs00523k

[39] Sushama R, Sadique Hussain M.D , Chandan M , Gurleen K . (2021).An Overview Of Monoclonal Antibodies And Their Therapeutic Applications. *Nat. Volatiles & Essent. Oils*, Vol.8(6): 4121-4130

[40] Ruei-Min L,. Yu-Chyi H , Ju Liu J , Chi-Chiu L , Han-Zen T, Hsin-Jung L , Han-Chung W . (2020).Development of therapeutic antibodies for the treatment of diseases". J*ournal of Biomedical Science* , Vol;27:1. DOI: 10.1186/s12929-019-0592-z

[41] Dimitrov D.S nd Marks J.D .(2009).Therapeutic Antibodies: Current State and Future Trends – Is a Paradigm Change Coming Soon?. *Methods in Molecular Biology*.Vol.525:1-13. DOI: 10.1007/978-1-59745-554-1_1

[42] Castelli M.S, Mc Gonigle P, Hornby P.J. (2019).The pharmacology and therapeutic applications of monoclonal antibodies. *Pharmacology Research & Perspectives*; Vol.7(6). DOI: 10.1002/prp2.535

[43] Lim C.Y, Lee K.J, Oh D.B, and Ko K .(2015)Effect of the developmental stage and tissue position on the expression and glycosylation of recombinant glycoprotein GA733-FcK in transgenic plants, *Frontiers in Plant Science*, vol. 5, article 778, 11 pages.(52). DOI: 10.3389/fpls.2014.00778

[44] Faye L, Landry Lerouge N.P, Gomord V, and Vezina L.(2021).La ´production de proteines ´ a usage biopharmaceutique dans les ` plantes, *Medecine/Sciences SYNTHESE ´*.vol. 17, no. 8-9, pp. 867– 877, (53). DOI:10.4267/10608/2021

[45] Song I.C, Kim D.S, Kim M.K, Jamal A, Hwang K.A, and Ko K.(2015).Comparison of total soluble protein in various horticultural crops and evaluation of its quantification methods," Horticulture, *Environment, and Biotechnology*. vol. 56, no. 1, pp. 123–129, (54). DOI:10.1007/s13580-015-0097-y

[46] Ko K and Koprowski H.(2005). Plant biopharming of monoclonal antibodies," *Virus Research*. vol. 111, no. 1, pp. 93–100, 2005.(16). doi: 10.1016/j.virusres.2005.03.016.

[47] Ko K, Wei X, Crooks P.A, and Koprowski H, .(2004).Elimination of alkaloids from plant-derived human monoclonal antibody," *Journal of Immunological Methods*, vol. 286, no. 1-2, pp. 79–85(55). DOI: 10.1016/j.jim.2003.11.015

[48] Fischer R, Stoger E, Schillberg S, Christou P, and Twyman R.M. .(2004).Plant-based production of biopharmaceuticals. *Current Opinion in Plant Biology*,vol. 7, no. 2, pp. 152–158, (57). DOI: 10.1016/j.pbi.2004.01.007

[49] Faye L, Boulaflous A, Benchabane M, Gomord V, and Michaud D.(2005).Protein modifications in the plant secretory pathway: current status and practical implications in molecular pharming," *Vaccine*, Vol. 23, no. 15, pp. 1770–1778, (58). 2004- DOI: 10.1016/j.vaccine.2004.11.003

[50] Rodolfo V , Leonardo G, Sigifredo P, José B, Biunayki R, Tatiana A, Otto M, Orlando H, William F, Merardo P, Vladimir L, Marbelis L, Yasser H, Cristina G, Lorely M, Olga G, Rafael S, Alfonso A, Déborah G, Rolando P, Jorge L.V, Carlos B. (2003).Large-scale purification ´ of an antibody directed against hepatitis B surface antigen from transgenic tobacco plants, *Biochemical and Biophysical Research Communications*,2003, Vol. 308, no. 1, pp. 94–100, (77). DOI: 10.1016/s0006-291x(03)01335-4

[51] Ko K, Steplewski Z, Glogowska M, and Koprowski H . (2005)Inhibition of tumor growth by plant-derived mAb," *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 102, no. 19, pp. 7026–7030, 2005.(30). DOI: 10.1073/pnas.0502533102

[52] Margarita T, Blanca L, Sabine L.R, Immaculada L.T, Miriam B, Pau M, Ann W.P, Markku S, Peter B Heifetz, Dolors Ludevid M . .(2009).Eukaryotic protein production in designed storage organelles," *BMC Biology*, Vol. 7, article 5, (82). DOI: 10.1186/1741-7007-7-5

[53] MacEwan S.R, Hassouneh W, and Chilkoti A. , (2014).Non-chromatographic purification of recombinant elastin-like polypeptides and their fusions with peptides and proteins from Escherichia coli," *Journal of Visualized Experiments*, no. 88, Article ID e51583, (83) DOI: 10.3791/51583

[54] Joensuu J.J, Conley A.J, Linder M.B, and Menassa R.(2020).Biosep aration of recombinant proteins from plant extract with hydro phobin fusion technology," *Methods in Molecular Biology*, vol. 824, pp. 527–534.2020. DOI: 10.1007/978-1-61779-433-9_28

[55] David Z and Louis W .(2020). Monoclonal Antibodies in Cancer Therapy". *Antibodies j*, 9(3), 34; DOI: 10.3390/antib9030034

[56] Ralf L, Tobias R, Roman K, Patrick H, Susanne M, Benno R, Matthias F, Oliver T, Grit L, Doris Rau, Evelyne S, Ines H, Andreas W, Thomas U, Patrick A.B, Peter K.(2010).T Cell-Engaging BiTE Antibodies Specific for EGFR Potently Eliminate KRAS- and BRAF-Mutated Colorectal Cancer Cells". *Proc. Natl. Acad. Sci. USA* , 107, 12605–12610. DOI: 10.1073/pnas.1000976107.

[57] Hagop K, Anthony S, Nicola G, Adele K.F , Andre C.S, Josep-Maria R, Andrew W, Hervé D, Robin F, Renato B, Önder A, Migue A.S, Julie B, Fatih D, Ewa L.M, Alessandro R, Xavier T, . Heinz-August H, Monika B, Wolfram K, Brent L.W, Alex F, Dirk N , Christopher H, Zachary Z, Max S.T . (2017).Blinatumomab versus Chemotherapy for

Advanced Acute Lymphoblastic Leukemia". *N. Engl. J.* Med. 376, 836–847. DOI: 10.1056/NEJMoa1609783

[58] Redman J.M, Hill E.M, AlDeghaither D, Weiner L.M.(2015).Mechanisms of Action of Therapeutic Antibodies for Cancer". *Mol. Immunol*.Vol.67, 28–45. DOI: 10.1016/j.molimm.2015.04.002

[59] Sushama R, Md Sadique H, Chandan M, Gurleen K..(2021).An Overview Of Monoclonal Antibodies And Their Therapeutic Applications". *Nat. Volatiles & Essent. Oils*; Vol.8(6): 4121-4130.

[60] Tigabu D, Endale B and Haben F.(2020).Monoclonal Antibody and its Diagnostic Application- Review .*BioMedical J.*, V. 30- Issue 4. DOI: 10.26717/BJSTR.2020.30.004997

الاجسام المضادة وحيدة النسيلة : انتاجها وتطبيقاتها– مراجعة

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الخلاصة:

الأجسام المضادة وحيدة النسيلة هي غلوبولينات مناعية تتمتع بمزايا كبيرة في مجال الكيمياء الحيوية والمناعة والتكنولوجيا الحيوية وتعرف أيضًا باسم الأجسام المضادة الفأرية لأنها تنتج بواسطة الفأر. نظرًا لصعوبة إنتاجها على عكس الأجسام المضادة متعددة النسيلة، فهي ثمينة (باهظة الثمن) مقارنة بالأجسام المضادة متعددة النسيلة. يتم إنتاجها أيضًا بتقنية الورم الهجين التي اكتشفها جورج كوهلر وسيزار ميلستين عن طريق تمنيع الفأر أولاً، ثم استخراج خلايا البلازما من الطحال ودمجها مع خلايا المايلوما (الخلايا السرطانية)، وأخيراً إنتاج خلايا الورم الهجين. أثناء عملية التطعيم (التمنيع) للفئران، يجب ألاخذ بنظر الاعتبار الرفق. لاجسام المضادة أحادية النسيلة تطبيقات بارزة في التشخيص، لذلك يتم دمج الأجسام المضادة وحيدة النسيلة في تقنيات التشخيص (المسح المناعي ، ELISA، اختبار التألق المناعي، والكيمياء المناعية) في تشخيص أمراض الماشية. تعتبر الأجسام المضادة وحيدة النسيلة مهمة في الاختبارات التشخيصية للكشف عن المستضد أو الجسم المضاد ضد الميكروبات. يعد استخدام الأجسام المضادة وحيدة النسيلة (MAbs) لعلاج مجموعة واسعة من الأمراض في طليعة الدراسات الطبية من خلال تطور العلاج التخصصي. منذ أن تمت الموافقة على أول علاج بالاجسام المضادة وحيدة النسيلة للاستخدام السريري في عام 1975، تطورت اليات انتاج MAbs بمعدل متسارع وتبلغ قيمتها الآن المليارات.

يتم تطوير الاجسام المضادة وحيدة النسيلة حاليًا، والتي تكون جزء من المسار العلاجي وضمان خصائصها المميزة. يمكن استخدام الاجسام المضادة وحيدة النسيلة لعلاج مجموعة متنوعة من الأمراض، بما في ذلك الالتهابات الفيروسية، وتسمم الدم، والتسمم، وإدمان المخدرات، والسرطان، وأمراض المناعة الذاتية، والربو، وألكثير من الامراض. ونتيجة للترخيص باستخدام أدوية جديدة لعلاج مجموعة متنوعة من الأمراض التي تصيب الإنسان، شهد سوق العلاج بالأجسام المضادة توسعا هائلا.

الكلمات المفتاحية : الاجسام المضادة وحيدة النسيلة ، مستضد ،ورم هجين ، خلايا بائية