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APTAMERS IN BREAST CANCER: ADVANCES IN TARGETED DIAGNOSIS, THERAPEUTIC STRATEGIES, AND NANOMEDICINE APPLICATIONS

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ABSTRACT

Breast cancer is still a major worldwide health concern that requires novel techniques to both diagnosis and treatment. Single-stranded oligonucleotides called aptamers have shown great promise in the fight against breast cancer because of their high affinity and selectivity in attaching to target molecules. This abstract delves into the various functions of aptamers in the treatment of breast cancer, with an emphasis on their use in targeted therapies and diagnostics. Compared to traditional therapeutic agents, aptamers have several benefits, such as minimal immunogenicity, high specificity, and the capacity to target a variety of biomarkers linked to the advancement of breast cancer. They can be made to attach to cancer cells only, preventing tumour growth and metastasis and reducing unintended effects on healthy organs. Additionally, aptamers can be coupled with other payloads, such as imaging agents, nanoparticles, or chemotherapeutic medicines, to improve their therapeutic efficacy and allow for targeted administration to tumour locations. Apart from their promise as therapeutics, aptamers have transformed the field of breast cancer diagnostics by acting as precise and sensitive biomarkers for the identification and tracking of the illness. Breast cancer biomarkers can be quickly and accurately identified with the use of aptamer-based biosensors and imaging probes, which can lead to early detection and individualised treatment plans. Additionally, aptamers can be used in liquid biopsy tests to find circulating tumour DNA or cells, which can help with prognostication and treatment selection. All things considered, aptamers are a promising family of chemicals for the targeted diagnosis and therapy of breast cancer. In the fight against breast cancer, their adaptability, specificity, and low toxicity make them indis-

pensable instruments in the creation of cutting-edge therapies and diagnostic systems, which will eventually improve patient outcomes and quality of life.

KEYWORDS: Aptamers, Breast cancer, Targeted Therapeutics, Biomarkers, Tumour targeting, Biosensor, Treatment Strategies.

1. INTRODUCTION

Aptamers are single-stranded DNA or RNA oligonucleotides that can bind to molecular targets with a high affinity by a selection procedure known as SELEX (Systematic Evolution of Ligands by Exponential enrichment) [1,2]. Almost any target, including metal ions, tiny compounds like medications or peptides, proteins, viruses, bacteria, entire cells, or even targets inside of living creatures, can have an aptamer selected for it (reviewed in) Aptamers are a tested substitute for antibodies in the activation or inhibition of processes, or in the targeted administration of imaging or therapeutic substances. Their affinity and specificity are comparable to those of typical antibodies. Additionally, aptamers are more advantageous than antibodies in several ways, including low toxicity and immunogenicity, high stability, simplicity of synthesis, modification, and functionalization. Aptamers are therefore perfect instruments for the creation of cutting-edge approaches in the targeted diagnosis and treatment of cancer. Using the conventional SELEX method, aptamers have been produced against entire cells or purified proteins [3-6]. To this aim, previously delivered cytotoxic siRNAs to prostate cancer cells selectively using an RNA ligand (aptamer) that binds the prostate cancer surface antigen PSMA. The aptamer carrying its siRNA payload (aptamer-siRNA chimaera) is endocytosed when it binds to PSMA on the surface of prostate cancer cells. The aptamer-siRNA chimaera serves as a substrate for the RNAi pathway protein Dicer once it has entered the cell. This results in the death of PSMA+-prostate cancer cells in culture and in vivo as well as the silence of the siRNA target gene [7-13]. One possible substitute source of molecules for focused therapy is aptamers. Functional short single-stranded non-coding RNA or DNA known as aptamers that can bind to certain targets with a high degree of affinity [14-20]. They are created in vitro using the SELEX (Systematic Evolution of Ligands by Exponential enrichment) technique, and through the formation of numerous secondary structures such the stem, loop, hairpin, bulge, pseudoknot, and G-quadruplex, they are able to recognise different targeted molecules [21]. Aptamers have several advantages over antibodies, including excellent stability, non-immunogenicity, and specificity and affinity. They may also be inexpensively and quickly altered to target a wide range of chemicals, earning them the moniker "chemical

antibodies [22-25]. Ellington and Szostak (1990) reported that an extensive combinatorial library yielded aptamers, a large collection of randomly sequenced RNA molecules that uniquely bonded chemical dyes [26]. A single-stranded DNA or RNA molecule known as an aptamer fold into a distinct tertiary structure to interact with particular targets; the complimentary forms of the aptamer and the target enable binding. Aptamers are tiny, easy to synthesis, fully designed, have little immunogenicity, and have great chemical stability when compared to other ligands [27]. Aptamers are appealing for targeted therapy because of these qualities. Thus far, several aptamers have been evaluated and have demonstrated significant promise for a variety of uses, such as prognostics, therapeutics, and cancer and viral disease treatment in humans [28]. Aptamers are categorised as either RNA aptamers or DNA aptamers. Research on RNA aptamers was concentrated in the early stages of the development of aptamers. Due to their distinct tertiary structure, RNA aptamers can bind more tightly and specifically to targets because of their single-strand structure. One advantage of RNA aptamers is that they are typically smaller than DNA aptamers, which facilitates the efficient delivery of drugs and other ligands to their targets. Numerous studies have shown that RNA aptamers are more capable of binding to specific targets [29,30]. Aptamers are single-stranded DNA or RNA oligonucleotides that have evolved from a variety of targets, including proteins, small molecules, ions, cells, and even tissues. They are frequently referred to as "chemical antibodies"[31-36]. Numerous biological domains, including biosensors, molecular imaging, drug transport, targeted therapy, disease detection and diagnostics, and tissue engineering, have made extensive use of aptamers [37-49].

2. CELL SELEX

The technique of using live cells to choose aptamers for target identification is known as "cell-SELEX." Consequently, cell-SELEX is an especially effective screening method for numerous uses, such as cancer treatment and research [50,51,52]. When expressed on the cell surface, these aptamers produced by a single purified protein might not, however, be able to recognise the same target in its native shape. Aptamers with high affinity and specificity for cells have been successfully created to circumvent this drawback, indicating that complex targets like cells and tissues are compatible with the SELEX process [53,54]. Cell SELEX is the name given to this improved SELEX procedure that uses entire living cells as targets. Researchers can now produce aptamers that specifically target proteins on the cell surface thanks to the development of the Cell SELEX method [55]. or certain cancer cell types, even in cases when the identity of the biomarker protein is unknown [56]. There are numerous

benefits to using cell SELEX to make aptamers. First, it has made it possible to identify aptamers in their natural settings, preserving both their biological roles and original conformations. Secondly, the process of selection can be executed without antecedent cognizance of the quantity or categories of proteins present on the target surface cell. Lastly, the chosen aptamers may bind to some unidentified surface proteins or biomarkers, facilitating the identification of novel biomarkers [57-60]. Different types of living pathogenic organisms were employed as cell SELEX targets [61-71]. Using African trypanosomes, Trypanosoma brucei, a live harmful organism, the first instance of cell SELEX was carried out in 1999 [72]. Using a novel cell SELEX technique, chosen aptamers were obtained by employing American trypanosomes, Trypanosoma cruzi, another living parasite. In order to prevent interactions between the parasite and host cell, the authors sought to produce aptamers that would compete with matrix molecules for binding to the parasite. The process produced aptamers that were specific for the target parasite, and the in vitro invasion assay, which employed monkey kidney cells, validated the predicted inhibitory action of multiple aptamers [73]. One of the targets for cell SELEX that has been studied the most is cancer cells. Numerous aptamers have been produced up to this point against various cancer cell types, such as lymphocytic leukaemia, myeloid leukaemia, liver cancer, and lung cancer [74-79].

3. Selection of specific aptamers using SELEX

Gold and Tuerk in 1990 [80] became the first to identify two RNA sequences from a random RNA library that had a binding affinity for T4 DNA polymerase in vitro, and they named the process Systematic Evolution of Ligands by Exponential enrichment (SELEX). Szostak and Ellington at the same time [81] created the term "aptamer" by separating RNA subpopulations from a vast combinatorial library of 1010 random sequence RNA molecules that had a distinct affinity for binding different chemical dyes. Since then, aptamer selection in vitro has extensively utilised the SELEX approach. standard SELEX protocols typically consist of the following steps: (1) designing and synthesising a random single-stranded (ss)DNA or RNA library; (2) binding to the target; (3) elution; (4) PCR amplification; (5) preparing a single-stranded oligonucleotide library; (6) several selection cycles; (7) cloning and sequencing; and (8) aptamer identification [82]. Negative selection is typically required in order to eliminate non-specific sequences prior to incubation with the targets. There are distinctions between the selection of RNA and DNA aptamers, though. Therefore, to obtain DNA aptamers, bound sequences are amplified using a standard PCR, and then ssDNA preparation is carried out to generate the secondary library. In contrast, reverse transcription PCR should be utilised for

RNA aptamers before the secondary random RNA library is prepared. The last few decades have seen a rapid advancement in SELEX techniques and aptamer uses across a range of fields. While the traditional SELEX is capable of successfully screening aptamers in vitro, the processes involved are time-consuming, arduous, and boring. In order to select aptamers against a variety of targets, such as proteins, peptides, tiny chemical compounds, metal ions, bacteria, cultured cells, and even heterogeneous in vivo targets, several highly efficient modified SELEX approaches have been devised [83-91]. SELEX techniques are classified into three categories based on the type of target: in vivo SELEX, Cell-SELEX, and purified target-based SELEX [92,93].

4. Breast cancer biomarkers

Breast cancer is a broad category of tumours with variable morphology and molecular makeup in individual cases. To determine which patients will benefit most from a certain treatment, it is essential to understand the molecular pattern of a tumour. The human epidermal growth factor receptor 2 and the oestrogen and progesterone receptors are used as validated clinical markers among the key biomolecular signatures; prognostic estimations and tracking the effectiveness of therapeutic interventions in patients with breast cancer are suggested by a number of other biomolecular signatures, including CA 15.3, CA 27.9, CEA, p53, Cyclin D, Cycline E, VEGF, MUC-1, and PDGR [94,95].

5. Application of aptamers

Aptamer and aptamer-nano material conjugates have garnered increased interest recently for their potential applications in cancer detection and treatment. Detecting cancer indicators and circulating tumour cells (CTCs) is a common application for aptamers that have affinity for tumour molecular biomarkers. This allows for prompt diagnosis, prognosis tracking, and targeted therapy. Consequently, a new path for personalised medicine of breast cancer has been opened up by the selection and application of a number of aptamers optimised for the disease in both diagnosis and treatment. Aptamer applications were the subject of a previously published review concerning aptamer-based diagnostics and targeted therapy in breast cancer [96]. Because of their exceptional qualities of high sensitivity and specificity towards the selected target, aptamers are an excellent choice for a molecular probe. Sullenger et al. provided the first evidence of aptamer usage as a medicinal agent in 1990 [97]. The local concentrations and effectiveness of cancer treatments have risen with the use of aptamers specific to cancer biomarkers. Due to its many advantages—such as stability for long-term storage, ease

of synthesis and use, and low immunogenicity and resistance—aptamers have grown in popularity as a method of treating and identifying specific tumours in recent years [98]. Trastuzumab and pertuzumab are being used in the treatment of breast tumours that express the human epidermal growth factor receptor 2 (HER2) [99,100]. Sadly, the development of resistance is a serious side effect of this medication [101].

a) Diagnostic applications of aptamers

aptamer-based breast cancer biomarker detection the identification of biomarkers is critical to the prognosis, monitoring of curative effects, and early diagnosis of breast cancer. HER2 is one of the most significant and widely used breast cancer-specific biomarkers that has been found. It is used both for molecular classification and for targeted therapy of breast cancer in clinics. Niazi and associates [102]. selected an anti-HER2 ssDNA aptamer H2 using Cell-SELEX, and it demonstrated a strong binding affinity to HER2 with a Kd of 270 nM. Next, they created a magnetic microbead-carbon nanotube-H2 hybrid system based on fluorescence for HER2 detection in vitro. They also showed that this system could be used to identify native HER2 protein in biological samples and solutions. Qureshi and associates [103]. The aptasensor demonstrated versatility and potential as a tool for early breast cancer diagnosis, since it was highly sensitive and could detect HER2 in human serum within a dynamic range of 0.2–2 ng/mL. Aptamers for breast cancer diagnostics were chosen using a variety of breast cancer indicators in addition to HER2 [104-108]. employed the HT-SELEX method to find an ERα-specific DNA aptamer that could be internalised by breast cancer cells that are ERα positive and locate in the nucleus. The results were compatible with IHC detection of ERα in breast cancer tissues strongly and moderately positive, or negative for ERα, when the aptamer was used to show ERα expression in breast cancer. Li et al [109]. SELEX as apotent methodology can facilitate biomarker discovery. The SELEX method is separated into two primary types, including protein-SELEX and cell-SELEX according on the sample used in the SELEX approach [110]. While cell-SELEX employs biomarkers in their native conformations as targets on the surface of living cells for aptamer isolation, SELEX uses purified proteins [111]. Targeted delivery of diverse cargoes into cells has been made possible by the use of aptamers that attach to cell markers [112]. The ability to target cells without prior knowledge of specific protein signatures is another benefit of cell-SELEX. There is a straightforward method for identifying these signatures [113]. Overexpressed in cases of breast tumours, HER2 is a significant biomarker and therapeutic target that is closely linked to poor prognosis and increased disease recurrence [114,115]. Moosavian et al. targeted

HER2-positive cells with a cell-SELEX technique to produce an enriched pool of RNA aptamers. The TSA14 aptamer was effectively identified, and it attached to the TUBO cell line (rHER2/neu+) with great affinity and selectivity while exhibiting no interaction with the CT26 cell line (rHER2/neu negative). The binding of the TSA14 aptamer to the extracellular domain of HER2 facilitated its interaction with TUBO cells. The findings suggested that the TSA14 aptamer, labelled with Cy5, would be a viable option for use as a diagnostic probe in breast cancer research [116]. In a different work, an RNA aptamer (S6) based on cell-SELEX was created for HER-2-overexpressing human breast cancer cells (SK-BR-3). Breast cancer cells were visualised using the TAMRA-labeled S6 aptamer. The outcome showed that the TAMRA-labelled S6 aptamer selectively attached to human breast cancer cells SK-BR-3, which overexpress HER-2, but not to MDA-MB-231, which expresses HER-2 less [117]. Using a straightforward and reasonably priced conventional dark field optical microscope (DFM), Huang and colleagues have effectively created aptamer-bioconjugated AuNPs (Apt–AuNPs) for the detection of three cancer epithelial cell lines: MDA-MB-231, HS578T, and MCF-7 (human breast adeno carcinoma). They targeted the platelet-derived growth factor (PDGF), which is overexpressed in cells with malignancies and developmental defects, with highly specific DNA aptamers (34-mer, Kd = 0.1–10 nM) [118]. The Apt-AuNPs aggregated in response to PDGF, producing bright yellowish dispersed patches that make it easy to identify individual cells. Additionally, they discovered that Apt-AuNPs might inhibit the proliferation of cancer cells while having no negative effects on healthy cells, supporting the idea that aptamer-bioconjugated NPs could be useful in the treatment of cancer [119]. Aptamers are showing increasing promise as a cancer imaging and diagnostic tool. Aptamer-nanoparticle (Apt-NP) conjugates are among the most useful systems for cancer diagnostics, as is well known. These conjugates can be used to search for cancer cells in complicated bodily fluids like blood and serum. Cancer cells are identified with great sensitivity and selectivity when using aptamers, and nanoparticles shield their nuclease activity. based on Borghei's studies. In order to couple AS 1411 aptamer nucleotides with gold nanoparticles (AuNP) and identify MCF-7 breast cancer cells more sensitively, colorimetric technique has been devised. Aptamers are ensnared because of their affinity for the nucleolin receptors found on cancer cells. Because the AS 1411 aptamer bound to breast cancer cells, it was taken out of the solution [120]. AS1411, a 26-base guanine-rich oligonucleotide, is referred to be an anti-nucleolin aptamer. It forms a stable dimeric G-quadruplex structure and selectively binds the target nucleolin receptors that are overexpressed on cancer cells. Since normal cells lack or have less nucleolin receptors than cancer cells, nucleolin may be used as a tumour biomarker

to differentiate between the two types of cells [121,122]. Therefore, in the future, a particular interaction between AS1411 and nucleolin may aid in the extremely precise and efficient targeting of therapeutic medicines to cancer cells [123,124]. Aptamers have also been used to find a number of biomarkers, mostly because they can be chosen without revealing their chemical identity beforehand. Utilising the biotinylated aptamer sgc8, PTK7 was found in a large number of cancer cells. Further investigation is warranted about PTK7, a pseudokinase devoid of tyrosine kinase activity. The identification of distinct kinds of PTK7 expression in both cancer and numerous healthy cells was made possible by the use of aptamers. The development of cancer is linked to upregulated PTK7 expression, which raises the possibility of using it as a diagnostic or therapeutic marker [125].

b. Therapeutic Application of Aptamers in Breast Cancer

Something that directly affects the target is called a therapeutic agent. Aptamers can affect the physiological functions of the targeted protein or mRNA, including the start of apoptosis, by modulating their performance [126-128]. used glutathione-attaching RNA aptamers to cause breast cancer tumour cells to undergo apoptosis. Reactive oxygen species (ROS), which control caspase activity in breast tumours, were collected by the aptamers. The capacity of the AS1411 aptamer to bind the Bcl-2mRNA-attaching protein nucleolin to induce Bcl-2 gene cytotoxicity and instability in MDA-MB-231 and MCF-7 breast tumours was evaluated [129,130]. The AS1411 aptamer has the potential to inhibit Bcl-2 gene survival in tumour cells by suppressing the homeostasis of MDA-MB-231 and MCF-7 cells. Additionally, it may prevent nucleolin from binding to the whole AU region of the Bcl-2 gene, which might ultimately initiate an apoptotic cascade. Varshney and associates [131]. Aptamers are great candidates for molecular probes because of their unique method, which is characterised by high sensitivity and specificity to a specific target. Aptamers as therapeutic agents are also being employed more frequently in the treatment of breast cancer, as Sullenger et al.'s 1990 demonstration showed. Sung-Chun Kim's group was able to bind the HER2-positive BT-474 breast cancer cells, but not the MDA-MB-231 breast cancer cells, by synthesising RNA aptamers specific to HER2 [132]. The anticancer drug DM1 was coupled with an aptamer specific for HER2 using a cleavable disulfide linker. HER2 RNA aptamers were more stable than unmodified RNA aptamers after being fluorinated with pyrimidines [133]. In addition, aptamers are being developed by researchers to target interactions with cancer cells in order to treat cancer. Aptamers, on the other hand, can be created to cure cancer by influencing the immune system and obstructing the proliferation of cancer cells indirectly. The microenvironment and tumour

cells express platelet-derived growth factor receptor β (PDGFRβ), which is substantially expressed in invasive triple negative breast cancer (TNBC). In 2020, Simona et al. used a high-efficacy PDGFRβ aptamer to effectively suppress tumour growth and metastasis in mice models of TNBC. Anti-programmed cell death-ligand 1 monoclonal antibodies (mAbs) and PDGFRβ aptamer are therefore coupled as a novel treatment that was investigated in TNBC. According to the aptamer's cross-reactivity between mice and humans, anti-PD-L1 mAb on TNBC cells has its anti-proliferative effects amplified. Furthermore, when attached to active human and mouse lymphocytes, the aptamer increases the cytotoxic activity of lymphocytes against cancer cells. The fact that the aptamer increases the efficacy of antibody-inhibited tumour growth and lung metastasis is a crucial advantage. Additionally, the medication blocks Akt and ERK1/2 signalling pathways, which increases intratumoral CD8 + T cells and decreases FOXP3 + Tregs [134]. Aptamers have the ability to bind to target proteins and influence gene expression. They can also signal cells to begin apoptosis or make them more susceptible to chemical treatments [135-139]. chosen two glutathione-binding RNA aptamers, whose Kd values were 41.8 and 48.9 nm, respectively. These aptamers were able to cause MCF-7 breast cancer cells to undergo apoptosis by increasing reactive oxygen species (ROS), altering intracellular glutathione levels, and activating caspase-3. This suggests that glutathione-binding RNA aptamers may be developed into potent therapeutic agents for the treatment of breast cancer. In a different investigation, the capacity of aptamer AS1411 to target the Bcl-2 mRNA-binding protein nucleolin to cause Bcl-2 mRNA instability and cytotoxicity in MCF-7 and MDA-MB-231 breast cancer cells was investigated [140]. The findings showed that aptamer AS1411 could effectively reduce the half-life of Bcl-2 mRNA in cancer cells, inhibit nucleolin binding to the AU-rich element 1 in Bcl-2 mRNA, thereby promoting mRNA destabilisation, and inhibit the growth of MCF-7 and MDA-MB-231 cells (but not that of normal mammary epithelial cells). According to these results, aptamer AS1411 is a potentially effective molecular swindler that competes with Bcl 2 mRNA for binding to the cytoplasmic nucleolin in breast cancer cells, ultimately leading to apoptosis. Varshney et al. conducted a study recently [141]. The therapy of cancer has also been the subject of substantial research on aptamer-nanomaterial conjugates [142]. A number of tailored treatments for breast cancer based on aptamer-nanomaterial conjugates have also been extensively studied in recent years and have shown significant promise for improving patient outcomes. Beqa and associates [143]. created a unique hybrid nanomaterial for the targeted photothermal treatment of breast cancer that is made up of single wall carbon nanotubes bonded to gold nanoparticles. The outcomes showed that 1.5 W/cm2 of laser irradiation at

785 nm could kill the targeted SK-BR-3 human breast cancer cells in less than 10 minutes. Gold nanorods (GNRs), which exhibit strong broad-band longitudinal surface plasmon absorption in the 600–1100 nm region, were utilised by researchers in a different investigation [144].

6. Aptamer as advanced therapeutic strategies in TNBC

TNBC cells express no progesterone, oestrogen, or ERBB2 receptors, which makes them a particularly difficult therapeutic target because of their high level of aggression and often poor response to treatment. Despite the fact that chemotherapy has advanced to a significant point in the triple-negative breast cancer treatment plan [145]. Reducing the negative effects of all available treatments is still necessary [146]. Furthermore, one of the main issues with metastatic cancer is drug resistance [147]. Much research on the use of aptamers in the diagnosis and treatment of TNBC have been published in recent years. More research is being done to improve aptamer-based therapies for TNBC. Although cisplatin is a potentially effective chemotherapeutic agent for treating TNBC as a neo adjuvant and metastatic treatment, its use is restricted by its poor bioavailability, systemic severe side effects, and drug resistance. By using a nanotechnology programme, cisplatin was effectively entrapped into polymerized nanoparticles (PNPs). To improve the targeted treatment, the nanoparticles were subsequently attached to the surface of EGFR selectivity and cellular internalising CL4 aptamers. TNBC's tumour targeting and antitumor efficacy are enhanced by this innovative cisplatin-loaded and aptamer-modified nanotherapy. It offers good promise for use in the detection and management of cancer [148]. Mesoporous silica nanoparticles were the basis for the medication co-delivery system that Vivo-Llorca et al. created to target TNBC cells. The objective is to overcome mcl-1-mediated resistance. Targeting TNBC cell lines, Apmuc1-coated nanoparticles overcame the navigoclax resistance [149]. While monoclonal antibodies have a lengthy history in the medical field, many benefits, and are used to treat a wide range of illnesses, there are drawbacks and inadequacies to consider. Numerous factors need to be taken into account, such as immunogenicity, stability, and high production costs. These problems are addressed by aptamers, which also have lower production costs, room temperature stability, faster synthesis and storage, and little immunogenicity. Patients with brain metastases from TNBC may benefit from aptamers that penetrate tissues more effectively. Using PD-L1 overexpressed or knockout TNBC cell lines, XQ-P3 was also developed using a unique loss-gain cell-SELEX approach. The aptamer binds specifically to PD-L1, suppressing PD-1/PD-L1 interactions.

When aptamers and paclitaxel were combined, T cell activity was restored, and PD-L1 over-expressed TNBC cells' cell uptake and anti-proliferative effectiveness were enhanced [150].

Future prospective

Aptamer integration in breast cancer research has great potential to advance therapeutic approaches and diagnostic techniques in the future. Through continuous improvements in aptamer engineering methods, including SELEX (Systematic Evolution of Ligands by Exponential enrichment), scientists will be able to create new aptamers that are more specific and aptamer-like for a larger variety of breast cancer indicators. Treatment methods that are less harmful and more successful can be developed by further customising these enhanced aptamers for targeted medication delivery. Additionally, the utilisation of aptamers in conjunction with cutting-edge technologies like immunotherapy and nanomedicine creates new opportunities for collaborative approaches to the treatment of breast cancer. Therapeutic outcomes could be improved by aptamer-conjugated nanoparticles' ability to get past biological barriers and increase medication penetration into solid tumours. Additionally, to harness the strength of the immune system for targeted cancer elimination, aptamers can be used in concert with immune checkpoint inhibitors or chimeric antigen receptor (CAR) T-cell therapy.

CONCLUSION

Aptamers' role in breast cancer research is expected to grow in the future due to a trajectory towards more accurate and customised methods of diagnosis and therapy. In the ongoing fight against breast cancer, researchers have the potential to greatly enhance patient outcomes and quality of life by utilising the special qualities of aptamers and combining them with state-of-the-art technologies.

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