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Review of the Application of Imaging Technology in the Recognition of Biosensors (Molecules)

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Abstract: This article will mainly introduce the application of applying medical imaging technology to assist in the identification of various biosensors (biomolecule).In today's cutting-edge cross field of medicine and biotechnology, the application of medical imaging technology to help the accurate identification of a variety of biosensors is showing great potential and value There are currently various mature and already put in use imaging technologies such as MRI, PET, etc. MRI uses powerful magnetic field and radio frequency pulse, which can obtain truly clear structural images of the human body; Pet can detect the positron annihilation signal generated by the decay of radioisotopes to monitor the metabolic activities in organisms with high sensitivity. More assistance is provided in identifying biometric components. The principle is to combine specific markers with sensors, and the combined system has specific properties such as radioactivity and magnetism that can be detected by medical imaging instruments. The review will talk about combine multiple technologies to identify biomolecule.

Keywords: Imaging, Recognition, Biosensors

1. Introduction

With the improvement of medical technology and people's awareness of the degree of disease cure, higher precision diagnostic methods need to be developed. And the integration of multiple disciplines provides a new way of thinking for medical diagnosis, breaking the shackles of a single disciplinary perspective. Nowadays, the gradual maturity of this technology has also undergone many exploratory processes. Early medical imaging technology was not yet mature and could only have a general understanding of the internal structure of the human body, such as X-ray ultrasound technology. The combination of the two technologies provided some basic ideas for the diagnosis of diseases. With the development of microelectronics and optoelectronics technology, numerous imaging technologies with excellent imaging capabilities have emerged, such as PET, MRI, PET/CT hybrid, and 3DUSCT, making the diagnosis of some complex patients more high definition (high-resolution). At the same time, biosensor technology has evolved from enzyme-based biomarkers to modern sensor detection technologies at nanoscale. The idea of integrating two technologies is not unfounded, as both detection functions can help determine the location of lesions and observe specific indicators. The joint development of the two has also contributed to the development of molecular imaging. Molecular imaging not only uses traditional imaging technology but also introduces molecular probes to identify markers [1]. By labeling specific biomolecules with probes, the principle of biosensors can be used to visualize the movement of specific molecules.

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2. Mechanism & sorts

2.1. The principle of PET technology

PET stands for Positron Emission Tomography. Firstly, some elements with short half- lives will be selected as positron emission sources. These radioactive elements enter the body by mixing with drugs, and their atomic nuclei begin to decay and release positrons. After moving a short distance within the human body, electrons encounter and annihilate electrons in the surrounding environment, producing gamma photons. The scintillation crystal inside the PET scanner receives visible light, and the photoelectric signal converter inside converts the light signal into an electrical signal for subsequent signal amplification and processing. In a short word, it can generate tomographic images of the distribution of radioactive tracers injected into the body [2].

2.2. The principle of MRI technology

MRI usually uses strong magnets and low-energy RF signals [3]. Many atomic nuclei have spin properties, which are macroscopically like the rotation of the Earth. This spin gives atomic nuclei angular momentum, which in turn generates magnetic moments. In the natural state, the direction of magnetic moment is random. When in a strong magnetic field, the magnetic moment will be aligned with the direction of the magnetic field, and this orientation distribution will reflect the atomic nucleus distribution of the overall organization. When the atomic nuclei are arranged in a regular pattern, radio frequency pulses (electromagnetic waves of a specific frequency) need to be released to the human body. When the energy of the pulses is absorbed, the atomic nuclei in a low energy state will transition to a high energy state, causing the macroscopic magnetic moment of the human body to undergo a uniform deviation. The direction of the deviation is related to the strength and time of the pulses. After the pulse ends, the energy of the atomic nuclei gradually releases into the surrounding molecular environment and returns to the low energy level. The direction of the macroscopic magnetic moment gradually returns to the same direction as the strong magnetic field. This process is called longitudinal relaxation. The component of the macroscopic magnetic moment perpendicular to the strong magnetic field gradually decreases, and this process is transverse relaxation. During the reduction of the component, induced current is generated in the coil, which will decrease with time. The several types of signals obtained in the previous process can only be processed and processed using image reconstruction algorithms to obtain the corresponding information. When obtaining information, MRI contrast agents are used to increase the signal intensity of human tissue, thereby enhancing the contrast with surrounding tissues.

2.3. Principles of biosensors

Biosensors consist of two parts: biomarkers and transducers. Biometric identification is used for specific recognition of target substances. For example, the specific binding of enzymes to substrates, the specific binding of antibody antigens, or the hybridization of nucleic acid molecules. These recognition processes are often accompanied by changes in parameters such as ion concentration, electron gain and loss, heat, light intensity, etc. By converting all these signals into electrical signals, quantitative analysis of the target substance can be conducted.

2.4. Combining medical imaging with biosensing principles

The mechanism is like molecular imaging, where molecular probes with specific recognition ability are first developed, which bind to the target molecule, and then tracking and typing are performed using imaging technology. This article introduces the combination of PET and MRI with biosensors.

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2.5. Sort

2.5.1. Radioactive nuclide molecular sensor

Labeling radioactive isotopes in biomolecules and imaging them using the radiation released by decay. This sensing technology is used in conjunction with PET.

2.5.2. Superparamagnetic iron oxide nanoparticles (SPIO) sensor

The superparamagnetic of SPIO refers to its ability to rapidly magnetize under the influence of an external magnetic field. After the external magnetic field disappears, its magnetism will quickly disappear, that is, it will quickly respond to changes in the magnetic field. After appropriate modifications, SPIO can have good compatibility with biomolecules and reduce rejection reactions.

3. Applications

3.1. Use MRI to identify PH biosensors

In MRI imaging technology, there is a substance called contrast agent, which is used to alter the relaxation characteristics of local tissues to improve imaging contrast. The reason for studying pH sensors is that various diseases and metabolic disorders can cause a decrease in tissue PH [4]. Furthermore, observing pH becomes the key and breakthrough point for judging the degree of disease and finding the location of lesions. The special energy harvesting mechanism of cancer cells produces lactate, and the accumulation of acidic metabolites produced by metabolic diseases can also lead to a decrease in pH. There are several ways to start the pH sensor.

3.1.1. Change the hydration degree of developer

The first is that the relaxation characteristics of the special functional groups contained in the developer will change due to the change of PH. The specific statement is that pH affects the coordination structure, the coordination structure affects the degree of hydration (the binding sites and number of contrast agent molecules and water molecules), and the degree of hydration affects the relaxation time. Take gadolinium with nine coordination structures as an example. To cause the relaxation of contrast agent, the phosphine containing ligand l mentioned in the cyrille at al. 's article was introduced [5]. This phosphine containing ligand is pH sensitive, which means its protonation state changes under different acid-base states. Protonation refers to the process of obtaining one or more protons, which may enhance the acidity of some acids. As shown in the figure 1, this is the Podand type phosphonate ligand LH6. This ligand contains phosphonate groups, which can obtain protons under acidic conditions and can accommodate two more water molecules, thereby improving the overall hydration degree. As the pH increases, a water molecule will be squeezed out to reduce the degree of hydration. Moreover, because the degree of hydration is related to the relaxation degree of the developer, this undoubtedly indicates a pH dependent change in relaxation degree.

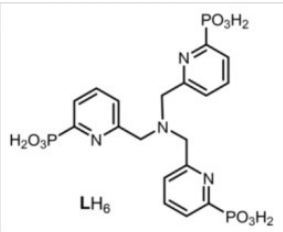

Figure 1: Podand type phosphonate ligand LH6 [6]

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3.1.2. Change the rolling rate of the developer in the solution

Unlike the first application, the second one tends to judge from the perspective of structural rigidity. Poly (L-ornithine) has good water solubility and carries a positive charge in aqueous solution. Its amino group undergoes protonation at higher pH conditions. This process promotes the formation of the alpha helix conformation. This structure is more stable in solution. This study uses a ratio of transverse to longitudinal like the figure 2, but it is not simply a ratio of relaxation values, but rather a ratio of the longitudinal contributions of transverse and paramagnetism to the proton relaxation rate of water. This more intuitively reflects the change in relaxation value as the solution concentration increases [7].

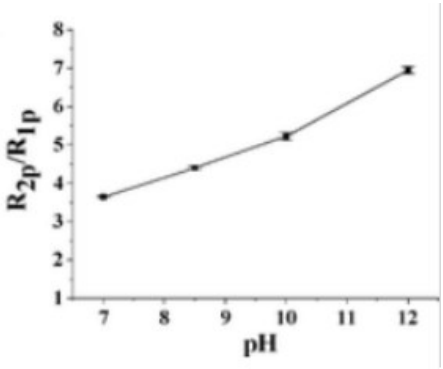

Figure 2: Variation of relaxation value [7]

3.2. Using MRI assisted detection of cell apoptosis

Due to numerous neurodegenerative diseases, autoimmune diseases, and cancers, apoptosis is an important indicator. Since tumors are the external manifestation of some cancers, and the formation of sexual tumors is related to abnormal apoptosis of cells, the specific relationship is that malignant tumors are promoted by abnormal apoptosis. This is because some cells that should have been cleared through apoptosis are able to survive and continue to reproduce. During the development of tumors, due to their unique mode of reproduction and other factors, tumors gradually acquire the ability to evade apoptosis. Due to the inability to directly detect apoptosis, it is particularly important to detect proteins related to apoptosis or other artificial markers. Annexin V-coupled ultra small superparamagnetic iron oxide (V-USPIO) is a new detection substance. This is a calcium dependent phospholipid binding protein with a high affinity for phosphatidylserine. Phosphatidylserine is enriched on the inner side of biological membranes, and during cell apoptosis, it reverses to the outer side. This change can be recognized by specific receptors on the surface of phagocytic cells, which in turn guide the elimination of phagocytic cells. So, the process of amino acid eversion is an important marker of early cell apoptosis. Superparamagnetic iron oxide is a known MRI contrast agent, which forms another probe that can be captured by MRI and detect apoptosis by coupling Annexin V. This contrast agent is Annexin V(figure3) bound carboxymethyl diethylaminoethyl dextran magnetite (CMEADM) USPIO particles. This experiment has confirmed that the reagent indeed has the potential for detection. At the clinical level, this diagnostic method provides a certain reference for patients to assess the apoptosis level of their own cells after chemotherapy and provides important imaging evidence for the diagnosis and treatment of diseases [8].

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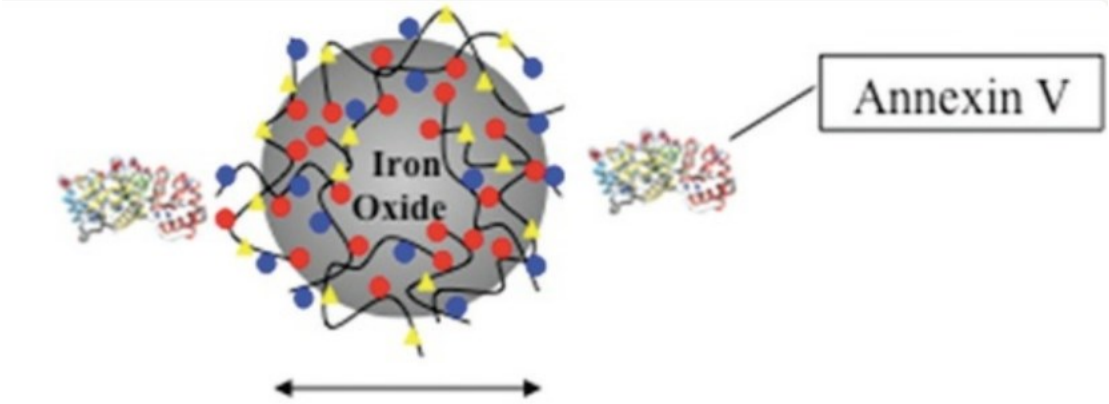

Figure 3: Annexin V [8]

3.3. Using PET to assist in the diagnosis of Alzheimer's disease

With the increasing trend of global population aging, the incidence of Alzheimer's disease is also on the rise. The pathogenesis of Alzheimer's disease is related to the accumulation of beta amyloid protein in the brain. The accumulated parts are called amyloid plaques, which can lead to further inflammatory reactions and neuronal damage. So, the detection and diagnosis of Alzheimer's disease are closely related to the detection of beta amyloid protein. Due to the deposition of some beta amyloid proteins during the normal aging process, to avoid misdiagnosis, some specificity that only occurs in Alzheimer's disease is taken advantage of. Moreover, this protein deposition has already occurred before the onset of cognitive impairment, so detecting this protein is relatively advantageous for early diagnosis of the disease [9]. Firstly, some suitable radioactive tracers will be selected to specifically bind to β - amyloid plaques. After these tracers are injected intravenously into the human body and bind with target molecules, they are captured by PET to produce distribution imaging in the brain, which achieves visualization processing of β - amyloid protein. As mentioned in the above literature, the overall diagnostic efficacy of β - amyloid protein is good, but its efficacy in distinguishing Alzheimer's disease from cognitive impairment may be poor, and there may be cases where mild cognitive impairment is identified as a disease.

3.4. Assist in biological research

The applications mentioned earlier are all related to direct disease diagnosis and control. The following will describe some applications related to biology and medical research.

3.4.1. Research on PET/MR combined imaging assisted neuroreceptor imaging

Studying neurotransmitter receptors is of great significance for a deeper understanding of nervous system function, such as explaining neural circuit function, exploring neural development, and aging. PET was chosen as a suitable auxiliary imaging technique because of its unique imaging that relies on biological metabolism. With precise localization and quantitative analysis of labeled isotopes, it provides a quantitative basis for studying the changes of neurotransmitter receptors in physiological and pathological states. PET/MR combined imaging technology has important performance in studying neural receptors. For example, in the dopamine system, [C] raclopride is used as a radioactive tracer that can specifically bind to dopamine D_2/D3 receptors. When the dopamine D_2/D3 receptor agonist tropinolole is given, it competes with the original dopamine receptor, resulting in a temporary negative CBV response. As shown in the figure 4.

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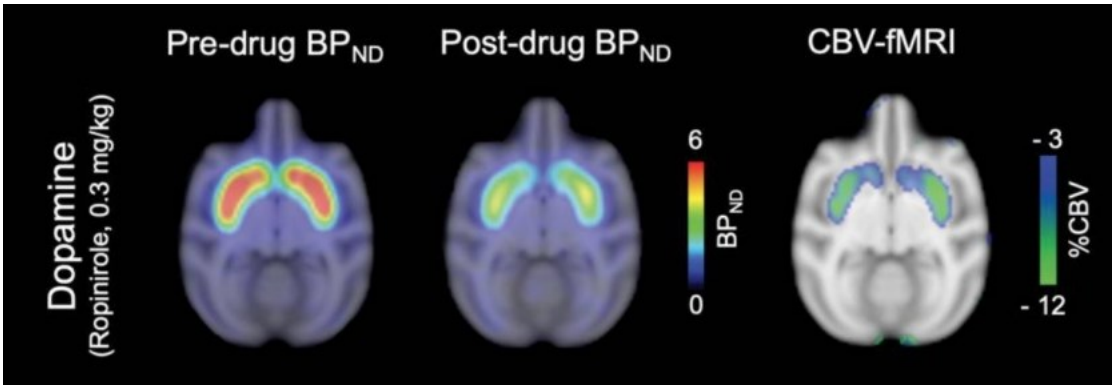

Figure 4: CBV rate [10]

Afterwards, experimental groups were added to study the opioid and serotonin systems. Similarly, multiple substances competing for receptors were used to observe the severity of CBV reactions after medication. PET/MR combined imaging technology can simultaneously present the dynamic changes in neurotransmitter receptor binding under drug stimulation and the corresponding changes in cerebral blood volume. These pieces of evidence undoubtedly provide similar guarantees for studying the mechanisms of neural receptors [10].

3.4.2. PET assisted cardiac receptor research

Due to the specificity of some drugs and diseases, as well as the key role of the heart as an organ, research on cardiac receptors is crucial. These can provide important ideas for guiding the development of treatment plans and exploring the pathogenesis of diseases. In this study, subjects were intravenously injected with radioactive tracers, namely [^{11} C] carfentanil ([^{11} C] CFN) and [^{11} C] - N-methyl-naphthalenedione ([^{11} C] MeNTI). To further verify the specific relationship between imaging results and opioid receptors, researchers conducted further blockade experiments. Five minutes before injection of [^{11} C] MeNTI, naloxone was injected as an opioid receptor antagonist, which can bind to opioid receptors. By observing the changes in imaging data before and after blockade, it can be confirmed that imaging results are indeed produced by the specific binding of tracers to opioid receptors. This study successfully achieved imaging of human cardiac opioid receptors using PET in vivo, which has important theoretical and practical significance. From a theoretical perspective, it provides intuitive imaging evidence for the in-depth study of the mechanism of action of cardiac opioid receptors in cardiovascular pathophysiological processes.

4. Conclusion

Two imaging techniques have achieved enormous success in assisting in the identification of biomolecules. In terms of disease diagnosis and research, early diagnosis, staging, and efficacy evaluation of tumors can be more accurately achieved through its high precision and imaging molecular dependence. In addition, research on neurological diseases, PET can label neurotransmitter receptor ligands to study their distribution and function, and MRI can provide valuable information on brain anatomy and function. In terms of molecular dynamic monitoring, a more comprehensive understanding of the dynamic changes of biomolecules in physiological and pathological states. For PET, it can be analyzed at the molecular level and precise quantitative analysis can be performed. For MRI, it has high resolution and many imaging parameters, which can analyze images from more angles, making multidisciplinary diagnostic methods possible without radiation hazards. When advantages are mentioned, there will inevitably be disadvantages. For PET, which appeared earlier, its imaging resolution is not high enough, and it is not clear enough for imaging some small tissues.

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Moreover, the types of tracers available so far are insufficient, and there are high requirements for operators to inject tracers. For MRI, the display of calcification and bony structures is poor. When the diagnostic target is diseases such as bone, the imaging is not clear. Due to the imaging principle being related to magnetic fields, it is affected by the patient's metal implants, and the imaging time is long, which is unfriendly to some elderly and children. In terms of imaging speed, CT is superior to MRI and can generate images quickly for analysis. Optical imaging has the advantages of using low energy, no radiation, and high sensitivity to signal detection, but compared to PET, it does not pose a radiation hazard.

References

[1] *Chen K, Chen X. Design and development of molecular imaging probes[J]. Currenttopics in medicinal chemistry, 2010, 10(12): 1227-1236.*

[2] *DiFilippo F P. Instrumentation and principles of imaging: PET[M]//Cardiac PET andPET/CT Imaging. New York, NY: Springer New York, 2007: 3-18.*

[3] *Van Geuns R J M, Wielopolski P A, de Bruin H G, et al. Basic principles of magneticresonance imaging[J]. Progress in cardiovascular diseases, 1999, 42(2): 149-156.*

[4] *Louie A. MRI biosensors: A short primer[J]. Journal of Magnetic Resonance Imaging,2013, 38(3): 530-539.*

[5] *Charpentier C, Salaam J, Nonat A, et al. pH-Dependent Hydration Change in a Gd-Based MRI Contrast Agent with a Phosphonated Ligand[J]. Chemistry–A EuropeanJournal, 2020, 26(24): 5407-5418.*

[6] *Charpentier, Cyrille, et al. "Phosphonated Podand Type Ligand for the Complexationof Lanthanide CationsPhosphonated Podand Type Ligand for the Complexation ofLanthanide Cations."European Journal of Inorganic Chemistry 2019.16 (2019): 2168-2174.*

[7] *Aime, Silvio, et al. "A R2/R1 ratiometric procedure for a concentration-independent,pH-responsive, Gd (III)-based MRI agent."Journal of the American ChemicalSociety 128.35 (2006): 11326-11327.*

[8] *Nishie, Akihiro, et al. "In vitro and in vivo detection of drug-induced apoptosis usingAnnexin V-conjugated ultrasmall superparamagnetic iron oxide (USPIO): A pilotstudy."Magnetic Resonance in Medical Sciences 18.2 (2019): 142-149.*

[9] *Ruan, Dan, and Long Sun. "Amyloid-β PET in Alzheimer's disease: a systematic reviewand Bayesian meta-analysis."Brain and Behavior 13.1 (2023): e2850.*

[10] *Sander, Christin Y., Hanne D. Hansen, and Hsiao-Ying Wey. "Advances insimultaneous PET/MR for imaging neuroreceptor function."Journal of cerebral bloodflow & metabolism 40.6 (2020): 1148-1166.*