An Analysis of Amyloid, Tau, and Inflammation in Alzheimer's Disease

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Abstract

Alzheimer's disease (AD) is a progressive brain disorder that leads to memory loss, cognitive decline, and difficulty performing daily activities. Although current treatments mainly focus on managing symptoms, understanding the underlying causes of the disease can lead to more effective therapies and earlier detection. This report examines the roles of amyloid-beta plaques, tau protein tangles, and neuroinflammation in the development and progression of Alzheimer's disease. Amyloid-beta plaques build up between neurons and disrupt communication, while tau tangles form inside neurons and block essential transport systems, leading to cell death. In addition, chronic neuroinflammation caused by overactive immune cells further damages brain tissue. By studying how these three factors interact, researchers can develop targeted treatments, such as antibody therapies, small-molecule drugs, and stem cell approaches, that aim to slow or stop disease progression. This research also supports the development of biomarkers, including protein levels in blood or cerebrospinal fluid and brain imaging techniques, which can detect Alzheimer's disease at an early stage before major symptoms appear. This report also covers how lifestyle modifications, such as diet, regular exercise, and proper sleep, can help lower the risk of AD or slow its progression (Kivipelto et al., 2018). Overall, a better understanding of the biological processes of AD and factors which can ameliorate AD progression offers hope for earlier diagnosis, improved treatments, and potentially preventing Alzheimer's disease in the future.

Introduction

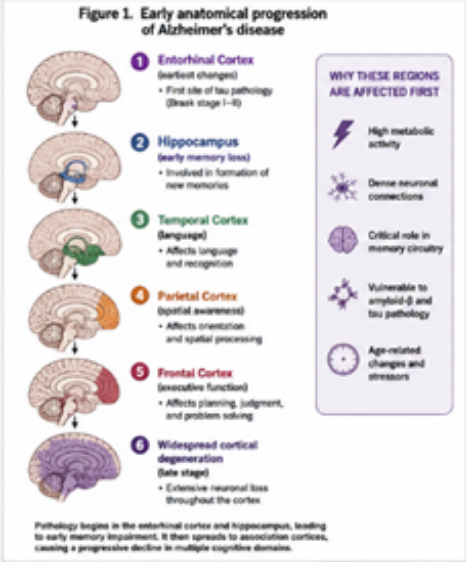
Alzheimer's disease (AD) is a serious and progressive disorder of the brain that slowly damages memory, thinking skills, and the ability to perform everyday tasks. It is the most common cause of dementia, which is a general term for the decline of mental abilities that is severe enough to interfere with daily life (Lane, Hardy, & Schott, 2018). In the United States, an estimated 7.2 million people aged 65 or older are currently living with Alzheimer's disease, which equates to approximately one in nine adults in this age group. Women are affected more often than men, making up almost two-thirds of diagnosed cases (Benilova, 2012). Researchers posit that sex differences exist because women live longer on average and experience major hormonal changes (Gordon, 2016). The number of people living with Alzheimer's continues to grow as life expectancy increases. Experts predict that by 2060, the number of people with Alzheimer's in the U.S. could rise to nearly 14 million if no major treatment breakthroughs occur. Currently, there is no cure for AD, and most treatments only address the symptoms rather than the underlying cause of the disease. In other words, medications can help patients remember things better or manage confusion, but they cannot stop the disease from progressing in the brain (National Institute on Aging, 2024). Age is the biggest risk factor for developing Alzheimer's disease, which is why the disease is becoming more common as the population ages (National Institute on Aging, 2024).

Neuropathology

The brain changes that occur in Alzheimer's disease develop gradually over many years. At first, neurons struggle to communicate effectively, and over time, they begin to die. This progressive loss of cells leads to noticeable brain shrinkage, particularly in areas involved in memory, such as the hippocampus. Three major biological changes contribute to Alzheimer's disease: amyloid plaques, tau tangles, and chronic inflammation. Amyloid plaques are sticky clumps of beta-amyloid protein that collect between neurons and disrupt communication. Tau tangles are twisted strands of tau protein found inside neurons that block the transport of nutrients and cause cell death. Both abnormal protein formations interfere with normal brain function. Chronic inflammation occurs when overactive immune cells in the brain accidentally damage healthy brain tissue and is associated with neurodegeneration, which is the gradual death of neurons or nerve cells (Chen et al., 2023). These changes interfere with brain function long before any noticeable symptoms appear (Braak & Braak, 1991).

As shown in Figure 1, the earliest structural and functional changes in Alzheimer's disease occur in the entorhinal cortex and hippocampus, two regions that are essential for learning and the formation of new memories. The entorhinal cortex serves as the primary communication pathway between the hippocampus and the rest of the cerebral cortex, allowing information from different parts of the brain to be integrated into long-term memories. These regions are affected first because their neurons are highly interconnected, have high metabolic demands, and are particularly vulnerable to the accumulation of abnormal proteins such as amyloid-beta and hyperphosphorylated tau. As neurons in these areas begin to degenerate, patients typically experience short-term memory loss, one of the earliest clinical signs of Alzheimer's disease. As the disease progresses, degeneration spreads to the temporal, parietal, and frontal lobes, leading to impairments in language, reasoning, decision-making, and other cognitive functions (Braak & Braak, 1991; Lane et al., 2018; Hampel et al., 2021).

Figure 1. Early Anatomical Progression of Alzheimer's Disease



How each part of the brain is affected by Alzheimer's

(Adapted from Hampel 2021)

Genetic Etiology of AD

Genetics influence a person's chance of developing Alzheimer's disease, but most cases are not completely inherited. Scientists group genetic involvement into two main categories: deterministic genes and risk genes (Corder et al., 1993; Goate et al., 1991).

The first category includes rare inherited mutations that directly cause Alzheimer's disease, usually leading to early-onset Alzheimer's (before age 65; Hardy & Selkoe, 2002). These mutations affect how the brain processes a protein called amyloid precursor protein (APP), which is normally cut into smaller pieces. When this cutting process goes wrong, it produces too much beta-amyloid, a sticky protein fragment that clumps together and forms plaques in the brain—one of the main features of Alzheimer's disease (Selkoe & Hardy, 2016).

Several specific mutations have been studied in mouse models. For example, the Swedish mutation of the APP gene (APPswe) causes cells to produce higher levels of beta-amyloid. Mice engineered with this mutation develop amyloid plaques much earlier than normal mice and show memory and learning problems (Oakley et al., 2006). Another example is the London APP mutation (V717I), which changes how APP is cut and increases the more harmful type of beta-amyloid. Transgenic mice with this mutation show early plaque buildup and changes in brain cell communication (Goate et al., 1991).

Other deterministic mutations affect the gamma-secretase complex, a group of proteins that also helps cut APP. Important genes here include presenilin-1 (PSEN1) and presenilin-2

(PSEN2). Mutations such as PSEN1 M146V and PSEN1 ΔE9 have been tested in mouse models and were shown to increase production of the more toxic beta-amyloid form (Aβ42). These mice develop plaques earlier, show neuron damage, and perform worse on memory tests (Yokoyama et al., 2022). PSEN2 mutations, such as PSEN2 N141I, have also been modeled in mice and lead to similar plaque formation and brain changes, though often more slowly (Yokoyama et al., 2022).

The second category includes risk genes, which increase the likelihood of developing Alzheimer's disease but do not guarantee it. The most well-known risk gene is the apolipoprotein E epsilon-4 (ApoE4) allele. ApoE helps transport fats and cholesterol in the brain. In mouse studies, animals with the ApoE4 version show reduced clearance of beta-amyloid and more inflammation in brain tissue compared to other ApoE types (Corder et al., 1993). In humans, having one copy of ApoE4 increases risk, and having two copies increases it even more — but many people with ApoE4 never develop Alzheimer's, and some people without it still do (Corder et al., 1993).

Overall, mouse model research has helped scientists understand how specific gene mutations change protein processing, speed up plaque formation, and damage brain cells. These models are important for testing possible treatments and learning how Alzheimer's disease develops at the biological level (Yokoyama et al., 2022; Oakley et al., 2006).

Diagnosis

Biomarkers

Biomarkers are measurable indicators that can help detect Alzheimer's disease before symptoms become severe (Hampel et al., 2021; Jack et al., 2018). One major group of biomarkers is proteins, including amyloid-beta and tau (Murphy & LeVine, 2010; Hampel et al., 2021). Changes in the levels of these proteins in blood or cerebrospinal fluid can signal early stages of the disease (Palmqvist et al., 2019; Brier et al., 2016). Tracking these protein changes is important for both diagnosis and research, as they can reveal how the disease is progressing or how a treatment is working (Hampel et al., 2021). Biomarkers are becoming an increasingly important tool because they provide a way to detect Alzheimer's at an early stage before significant brain damage occursJack et al., 2018; Brier et al., 2016).

Current diagnostic approach

Diagnosing Alzheimer's disease can be challenging because the symptoms usually develop slowly and can resemble normal aging or other health conditions (Lane, Hardy, & Schott, 2018). Memory lapses, confusion, or difficulty with problem-solving may be the first signs, but they are not always specific to Alzheimer's. To make an accurate diagnosis, doctors use several tools and tests together. One common approach is cognitive testing, which includes memory and

thinking assessments to evaluate learning ability, attention, language, and problem-solving skills (Jack et al., 2018)..

In addition to cognitive tests, brain imaging techniques are often used. MRI scans can show shrinkage in certain areas of the brain, while PET scans can detect the buildup of amyloid plaques, which are a hallmark of Alzheimer's (Brier et al., 2016; Villemagne, Fodero-Tavoletti, Masters, & Rowe, 2013). These imaging methods allow doctors to see physical changes in the brain that might explain a person's symptoms.

Doctors may also use blood tests or analyze cerebrospinal fluid from a spinal tap to check for biomarkers linked to Alzheimer's disease. These biomarkers can include abnormal levels of beta-amyloid or tau proteins, which are associated with the progression of the disease (Hansson et al., 2018; Hampel et al., 2021). Combining these tests helps doctors rule out other medical conditions, such as vitamin deficiencies, thyroid problems, or other forms of dementia, and provides stronger evidence for an accurate Alzheimer's diagnosis.

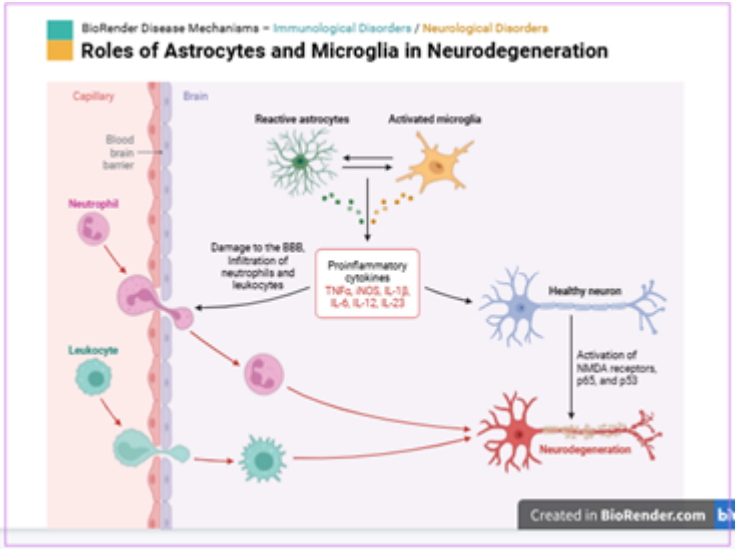
Overall, diagnosing Alzheimer's requires a careful, step-by-step approach that includes looking at symptoms, performing cognitive tests, examining the brain with imaging, and checking for biomarkers. Using all of these tools together increases the chances of identifying the disease early, which can help patients receive treatment and support sooner (Jack et al., 2018).

Proteins

Proteins in the brain and cerebrospinal fluid are some of the most important biomarkers for detecting Alzheimer's disease. Two of the key proteins are amyloid-beta and tau, which are directly involved in the formation of plaques and tangles, respectively. In Alzheimer's disease, amyloid-beta can accumulate in the spaces between neurons, while tau tangles form inside neurons. Measuring changes in the levels of these proteins in cerebrospinal fluid or blood can help identify the disease even before significant symptoms appear. For example, elevated levels of phosphorylated tau and reduced levels of amyloid-beta 42 in cerebrospinal fluid are strong indicators of Alzheimer's pathology. Tracking these protein levels over time can also help researchers monitor disease progression and test the effectiveness of new treatments. Protein biomarkers are therefore crucial for early detection, diagnosis, and research into therapies for Alzheimer's disease (Murphy & LeVine, 2010; Hampel et al., 2021).

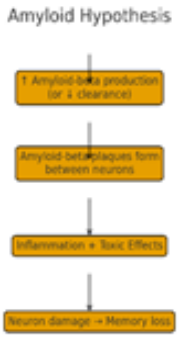
Mechanism of neurodegeneration

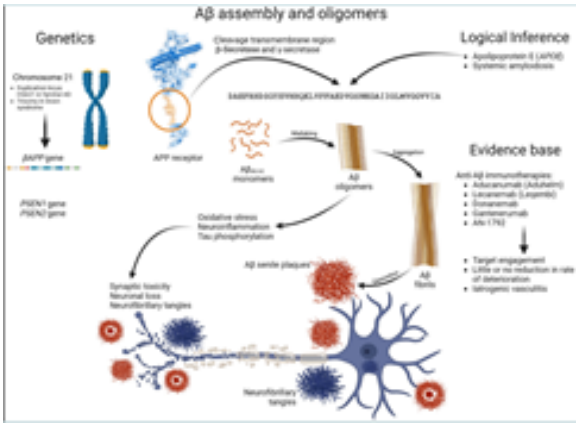
Figure 2. Roles of Astrocytes and Microglia in Neurodegeneration



As shown in Figure 2, microglia are important immune cells in the brain.

Amyloid hypothesis



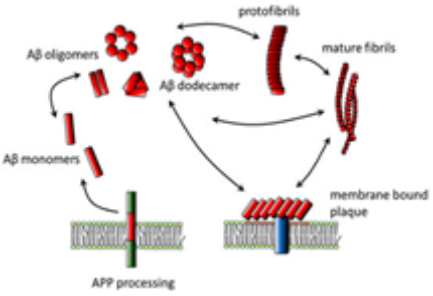


The steps of Amyloid Hypothesis and what it is about.

The amyloid hypothesis suggests that amyloid-beta buildup is the earliest biological event that triggers Alzheimer's disease, often beginning 15–20 years before symptoms appear. Small amyloid-beta oligomers are especially toxic because they interfere with communication between neurons before joining together to form larger plaques. These plaques activate microglia and astrocytes, the brain's immune cells, leading to chronic neuroinflammation. The inflammatory molecules released by these cells can then promote abnormal changes in tau proteins, allowing tau tangles to spread more rapidly throughout the brain. In many inherited forms of Alzheimer's disease, this sequence of amyloid-beta accumulation - neuroinflammation - tau pathology is

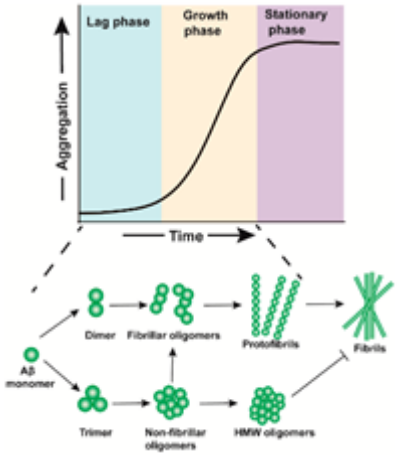
very common. However, scientists now recognize that Alzheimer's disease is more complex than originally thought. Rather than being caused by amyloid-beta alone, the progress of the disease is driven by continuous interactions among amyloid-beta, tau, and neuroinflammation (Selkoe & Hardy, 2016; Hampel et al., 2021; Chen et al., 2023).

Figure 3. Amyloid-beta aggregation and plaque formation in Alzheimer's disease.



How the oligomers affect the neurons and form large plaques

Figure 4. Amyloid-beta aggregation and fibril formation in Alzheimer's disease.



The growth and phases that take place during the formation of the fibrils from the amyloid beta monomers.

Abeta plaques

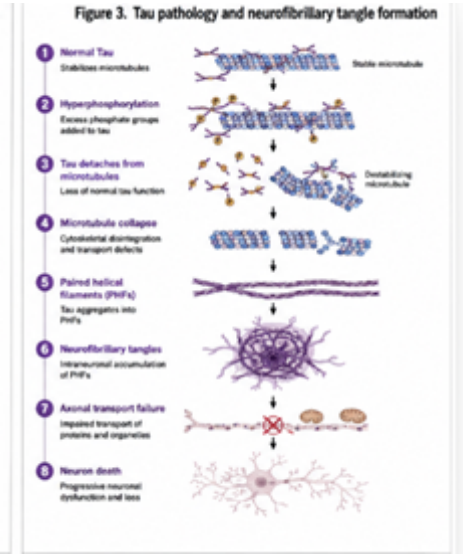
Abeta plaques are sticky clusters of a protein called amyloid-beta that build up between neurons, the cells in the brain that transmit information (Murphy & LeVine, 2010). These plaques interfere with how neurons communicate, which is a key factor in the memory loss and cognitive decline seen in Alzheimer's disease. Amyloid-beta proteins are first produced as single units called monomers. Normally, these monomers float harmlessly in the brain, but under certain

conditions, they can stick together to form small clusters called oligomers (Benilova, Karran, & De Strooper, 2012). These oligomers are especially toxic because they can damage neurons and disrupt the signals that allow brain cells to talk to each other.

Over time, the oligomers can join together to form long, thread-like structures called fibrils. Fibrils then accumulate into larger deposits known as plaques. As these plaques grow, they physically block connections between neurons and interfere with the flow of important chemical signals in the brain. In addition to disrupting communication, the plaques can trigger inflammation in brain tissue. This inflammation causes the brain's immune cells to become overactive. While immune cells are supposed to protect the brain, in this case, they can mistakenly attack healthy neurons, causing further damage (x).

Research using brain imaging techniques, such as PET scans, shows that people with high levels of amyloid-beta plaque buildup are more likely to experience memory problems and cognitive decline (Brier et al., 2016). Studies also suggest that plaques may appear years before symptoms become noticeable, meaning that amyloid-beta accumulation is an early step in the development of Alzheimer's disease (Selkoe & Hardy, 2016). Scientists continue to study Abeta plaques to better understand how they form, why they are toxic, and how targeting them could help prevent or slow the progression of Alzheimer's (Gulisano, Melone, Bernardo, & Ciotti, 2018).

Tau tangles



Tau pathology and how Tau tangles form in the brain.

Tau tangles form inside nerve cells when normal tau proteins become twisted and start clumping together (Chen et al, Li et al, Liu et al, & Wang et al, 2023). Under normal conditions, tau helps

maintain the internal structure of neurons, acting like scaffolding that keeps the cell stable and supports transport pathways for nutrients, proteins, and chemical signals. However, when tau proteins become abnormal, they lose their ability to function properly and instead stick together to form tangles (Villemagne et al, Fodero-Tavoletti et al, Masters et al, & Rowe et al, 2013). These tangles block the pathways that neurons use to transport essential materials, which disrupts communication between cells and prevents the neurons from staying healthy.

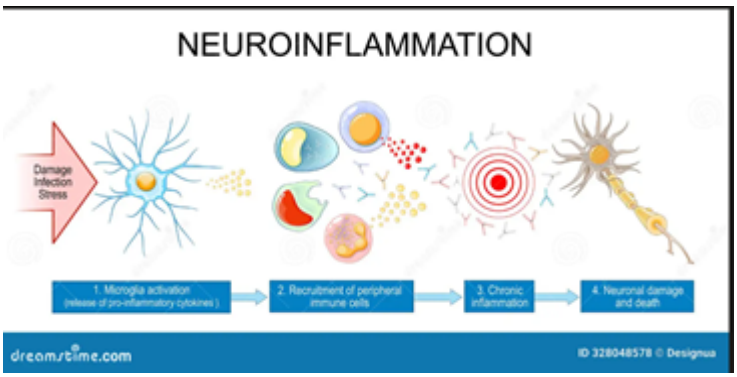
Unlike amyloid-beta, mutations in the tau gene are not a common cause of typical Alzheimer's disease. Instead, abnormal tau develops mainly because of excessive phosphorylation, a chemical process in which too many phosphate groups attach to the tau protein. This abnormal phosphorylation is driven by several protein kinases, including glycogen synthase kinase-3β (GSK-3β) and cyclin-dependent kinase 5 (CDK5), while phosphatases that normally remove phosphate groups become less active. As a result, tau detaches from microtubules, loses its normal stabilizing function, and begins to misfold into paired helical filaments that eventually accumulate as neurofibrillary tangles. In rare neurodegenerative disorders known as frontotemporal dementia, mutations in the MAPT gene directly cause tau aggregation; however, in Alzheimer's disease, abnormal phosphorylation rather than MAPT mutations is considered the primary mechanism leading to tau pathology (Gulisano et al., 2018; Chen et al., 2023).

Tau pathology also follows a characteristic pattern throughout the brain. According to the Braak staging mode (Chen et al., 2023; Yu et al., 2023) abnormal tau first appears in the transentorhinal cortex and entorhinal cortex, regions that connect the hippocampus with the cerebral cortex. It then spreads into the hippocampus, where memories are formed and consolidated, before progressing to the temporal, parietal, and frontal association cortices. These regions are affected first because they contain highly interconnected excitatory neurons with high metabolic activity, making them especially vulnerable to abnormal tau accumulation and the spread of misfolded tau proteins between neurons. As tau pathology advances through these neural networks, patients gradually develop worsening memory impairment, followed by deficits in language, reasoning, executive function, and eventually widespread cognitive decline (Braak & Braak, 1991; Villemagne et al., 2013; Hampel et al., 2021)

Over time, this disruption causes damage to the neurons and can eventually lead to their death. The spread of tau tangles through the brain follows a predictable pattern, often starting in areas involved in memory, such as the hippocampus, and then spreading to regions responsible for thinking and decision-making (Braak & Braak, 1991). Studies have shown that the amount and distribution of tau tangles are closely linked to how severe a person’s cognitive decline becomes. In fact, while amyloid-beta plaques are thought to trigger the disease process, tau tangles are more strongly associated with the progression of symptoms, including memory loss, confusion, and difficulty with problem-solving (Gulisano et al, Melone et al, Bernardo et al, & Ciotti et al, 2018). Understanding how tau tangles form and spread is an important area of

research for developing treatments that could slow or stop neuron damage in Alzheimer's disease (Chen et al., 2023).

Neuroinflammation



The steps in Neuroinflammation and how it leads to Neuronal damage.

Although amyloid-beta plaques and tau tangles are the most well-known features of Alzheimer's disease, research suggests that chronic neuroinflammation is also a major contributor to disease development and progression (Chen, Li, Liu, & Wang, 2023; Heneka, Golenbock, & Latz, 2015). Specialized immune cells called microglia normally protect the brain by removing damaged cells, clearing harmful proteins such as amyloid-beta, and responding to injury or infection. Another type of brain cell called astrocytes helps maintain the brain's chemical environment and supports normal neuron function. In Alzheimer's disease, however, both microglia and astrocytes can become chronically overactivated. Instead of protecting the brain, they continuously release inflammatory signaling molecules called cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), and interleukin-6 (IL-6), which damage nearby neurons and weaken the connections between them (Heneka et al., 2015).

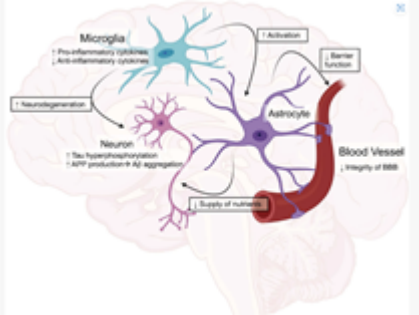
Although amyloid-beta accumulation has traditionally been considered the first step in Alzheimer's disease, researchers have found that the order of these biological changes is not always the same. In inherited forms of Alzheimer's disease caused by mutations in genes such as APP, PSEN1, or PSEN2, amyloid-beta plaques usually appear first. The buildup of amyloid-beta activates microglia and astrocytes, leading to chronic neuroinflammation. This inflammatory environment promotes abnormal changes in tau proteins, allowing tau tangles to spread more rapidly through the brain and causing progressive neuron loss (Selkoe & Hardy, 2016; Hampel et al., 2021).

However, evidence suggests that some cases of late-onset Alzheimer's disease may begin differently. Aging, reduced blood flow, infections, traumatic brain injury, or genetic risk factors such as ApoE4 can activate microglia before large amounts of amyloid-beta have accumulated. Once these immune cells remain activated for long periods, they become less effective at clearing amyloid-beta from the brain while continuing to release inflammatory molecules. As a result, chronic neuroinflammation can actually cause more amyloid-beta accumulation as well as abnormal tau phosphorylation, eventually leading to plaque formation, tau tangles, and neuron death (Heneka et al., 2015; Chen et al., 2023).

Because both pathways have been observed, many scientists no longer believe that every patient follows one single sequence of disease progression. Instead, Alzheimer's disease is increasingly viewed as a cycle. Amyloid-beta plaques stimulate neuroinflammation, neuroinflammation promotes additional amyloid-beta buildup and tau pathology, and tau tangles damage neurons, releasing signals that activate even more inflammation. Each process strengthens the others, creating a positive feedback loop that accelerates neurodegeneration and cognitive decline over time (Chen et al., 2023; Hampel et al., 2021; d'Errico, Meyer-Luehmann, & Schilling, 2020).

Reduced blood flow to the brain can also limit the delivery of oxygen and nutrients, making neurons more vulnerable to injury (Iadecola, 2013). In addition, oxidative stress, which involves harmful molecules called free radicals which are highly reactive, can damage brain cells and accelerate degeneration (Chen et al., 2023). In addition to the biological mechanisms underlying Alzheimer's disease, several genetic, lifestyle, and environmental factors contribute to an individual's risk of developing the condition. Genetic predisposition, particularly inherited variants associated with Alzheimer's disease, can significantly influence susceptibility. Lifestyle factors, including poor dietary habits, physical inactivity, smoking, and inadequate cardiovascular health, have also been linked to an increased risk of cognitive decline. Furthermore, environmental exposures, such as air pollution and certain neurotoxic substances, may contribute to neurodegeneration by promoting inflammation and oxidative stress. Although some risk factors, such as genetics and age, are non-modifiable, many lifestyle-related factors can be addressed through preventive interventions, highlighting the importance of healthy behaviors in reducing Alzheimer's disease risk (Kivipelto, Mangialasche, Ngandu, & Solomon, 2018). Because the processes are highly interconnected, scientists now view Alzheimer's disease as a complex condition with multiple causes rather than a disorder caused by a single protein or genetic mutation (Chen et al., 2023; Heneka et al., 2015).

Figure 7. The role of neuroinflammation in the development and progression of Alzheimer's disease.



A chain showing how inflammation in the brain leads to Alzheimer's

MRI/PET scans

Brain imaging is another key tool in diagnosing and monitoring Alzheimer's disease. MRI (Magnetic Resonance Imaging) scans can detect shrinkage in brain regions that are important for memory and thinking, such as the hippocampus and cortex. PET (Positron Emission Tomography) scans can detect the buildup of amyloid-beta plaques and tau tangles, providing a visual representation of the disease in the brain. These imaging techniques allow doctors to assess how far the disease has progressed and can help guide treatment decisions. Brain scans also play a critical role in research by helping scientists study the effectiveness of new therapies over time.

Treatment of AD

Treatment of Alzheimer's Disease

Antibody-Based Approach

One of the main approaches to treating Alzheimer's disease (AD) involves antibody-based therapies, which are designed to target specific proteins involved in the development of the disease. These laboratory-produced antibodies target amyloid-beta, a protein that can accumulate in the brain and form plaques, one of the key pathological features of Alzheimer's disease. The antibodies bind to amyloid-beta and help the immune system recognize and remove these plaques from the brain. This approach is considered a disease-modifying strategy because it aims to target an underlying feature of Alzheimer's disease rather than only treating its symptoms. Although antibody therapies do not cure the disease, they represent an important development in efforts to slow its progression and preserve cognitive function.

Current Treatments

Currently, there is no cure for Alzheimer's disease, so treatment focuses on managing symptoms, maintaining cognitive function, and improving quality of life. Medications can help address memory and thinking problems, while other treatments may be used to manage behavioral and psychological symptoms such as anxiety or depression. Non-drug approaches, including regular exercise, a healthy diet, social engagement, and structured memory routines, may also support overall cognitive and daily functioning (Kivipelto et al., 2018). In addition to these approaches, disease-modifying antibody therapies are now being used for some individuals with early Alzheimer's disease. These treatments represent a shift in Alzheimer's care from primarily managing symptoms toward also attempting to slow disease progression.

Latest Drugs – Antibodies

Recent advances in Alzheimer's research have led to the development of antibody-based drugs such as lecanemab, which specifically targets amyloid-beta in the brain. Clinical research has shown that lecanemab can reduce amyloid-beta plaque levels and modestly slow cognitive and functional decline in individuals with early Alzheimer's disease (van Dyck et al., 2023). However, these treatments do not reverse existing brain damage or cure Alzheimer's disease, and they may not be appropriate for every patient. Their development nevertheless represents an important step toward disease-modifying treatment. Alongside antibody therapies, researchers are also investigating emerging approaches such as stem-cell therapy, which aims to replace or repair damaged neurons and restore neural connections involved in memory and learning (Ou et al., 2024). Small-molecule drugs are also being studied for their potential to enter brain cells and target abnormal proteins, inflammation, and other mechanisms involved in Alzheimer's disease.

Stem-cell based

Stem-cell therapy is an emerging strategy that aims to replace damaged neurons with healthy new cells. Stem cells have the unique ability to develop into different types of cells, including neurons, which makes them a potential tool for repairing brain damage caused by Alzheimer's disease. In experimental studies, stem cells can be guided to integrate into the brain and restore some lost neural functions, including synaptic connections that are critical for learning and memory. While this approach is still largely in the research and clinical trial stage, it offers hope for not just slowing the progression of Alzheimer's disease, but potentially restoring some lost cognitive function in the future (Ou et al., 2024).

Small-molecule based approach

Small-molecule drugs represent a novel and promising approach in the treatment of Alzheimer's disease. These drugs are small enough to easily enter brain cells, allowing them to directly interact with abnormal proteins such as amyloid-beta and tau, which are central to the development and progression of Alzheimer's. By targeting these harmful proteins, small-molecule therapies aim to prevent their aggregation into plaques and tangles, which disrupt communication between neurons and contribute to cognitive decline. In addition to targeting proteins, some small-molecule drugs are designed to reduce neuroinflammation, which occurs when immune cells in the brain become overactive and mistakenly damage healthy neurons. Because these drugs can penetrate brain tissue efficiently, they are able to reach affected areas and potentially slow or stop the progression of the disease at a cellular level. Researchers are currently testing a variety of small-molecule compounds in both laboratory and clinical settings to determine their safety and effectiveness. While still largely experimental, this approach provides hope that Alzheimer's disease could one day be treated more effectively, rather than just managing its symptoms (Chen et al., 2023; Hampel et al., 2021; Selkoe & Hardy, 2016

Conclusion

Alzheimer's disease is a progressive brain disorder that causes memory loss, confusion, and cognitive decline, most often in older adults. The disease involves several biological processes, including amyloid-beta plaques, tau tangles, and neuroinflammation, as well as genetic, environmental, and lifestyle factors. Although scientists continue to study which process begins first, research shows that amyloid-beta, tau, and neuroinflammation are closely connected. In some cases, amyloid-beta buildup appears first and triggers neuroinflammation and tau pathology. In other cases, chronic neuroinflammation may occur earlier and contribute to amyloid-beta accumulation and abnormal tau changes. Regardless of which process begins first, these mechanisms eventually interact in a cycle that speeds up neuron loss and cognitive decline. Because these processes are so closely linked, it remains difficult to determine exactly how Alzheimer's disease begins and which biological changes should be targeted first. This complexity has made it challenging to develop treatments that consistently slow or stop disease progression.

Understanding how these biological processes work together has helped scientists develop better ways to detect and treat Alzheimer's disease. New biomarkers, including blood tests, cerebrospinal fluid analysis, and brain imaging, can help identify the disease before major symptoms appear. Researchers are also developing new treatments, such as antibody therapies, stem cell approaches, and small-molecule drugs, that target amyloid-beta, tau, and neuroinflammation. However, another challenge is diagnosing the disease early enough for these treatments to be most effective. Many people are not diagnosed until memory loss and

other symptoms become noticeable, by which point significant brain damage has already occurred. Although there is currently no cure for Alzheimer's disease, continued research offers hope for earlier diagnosis, more effective treatments, and new ways to slow or prevent the progression of the disease in the future.

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