An Aβ3-10-KLH vaccine decreases Aβ plaques and astrocytes and microglia activation in the brain of APP/PS1 transgenic mice

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This study aimed to investigate β‑amyloid peptide (Aβ) plaques and changes of astroglia and microglia in mice with Alzheimer’s disease (AD). In this study, 18 transgenic mice with amyloid precursor protein (APP)/presenilin-1 (PS1) were randomized into the Aβ3-10-KLH vaccine, Aβ1-42 vaccine, and phosphate-buffered saline (PBS) groups. The mice were injected at different time points. The Morris water maze test was used to identify the spatial learning and memory abilities of the mice. Immunohistochemistry was done to examine the Aβ, glial fibrillary acidic protein, and transmembrane protein 119 (TMEM119). Correspondingly, enzyme-linked immunosorbent assay (ELISA) was done to measure interleukin (IL)-1β and tumor necrosis factor (TNF)-α in the brain of transgenic mice. The Morris water maze results showed that both the Aβ3-10-KLH vaccine and the Aβ1-42 peptide vaccine could improve the cognitive function of APP/PS1 transgenic mice significantly. Aβ3-10-KLH and Aβ1-42 inoculations reduced Aβ load and suppressed astrocytes and microglia proliferation in the cortex compared with the PBS group. While there was no significant difference between the two groups, Aβ3-10-KLH and Aβ1-42 vaccines decreased the brain levels of IL-1β and TNF-α as compared with the PBS group, but without difference between the two vaccines. In conclusion, early immunotherapy with an Aβ vaccine reduces the activation of glial cells and deposition of Aβ plaque in the brain of transgenic mice.

Key words: Alzheimer’s disease, Aβ3-10-KLH vaccine, Aβ1-42 vaccine, amyloid-beta, astrocytes, microglia, APP/PS1 transgenic mouse

INTRODUCTION

Alzheimer’s disease (AD) is a neurodegenerative disorder and causes progressive deterioration in memory, daily behavioral function, and learning ability (Anand et al., 2014). One of the pathological changes in AD is the presence of deposition of amyloid plaques, the formation of neurofibrillary tangles (NFTs), and gliosis in the brain (Beach et al., 1989). The amyloid cascade hypothesis points out that the β-amyloid peptide (Aβ) accumulation triggers a series of reactions that include NFTs formation, neuron apoptosis, neuroinflammation, and gliosis (Selkoe and Hardy, 2016). Astrocyte is the main type of glia in the central nervous system (CNS) and works to maintain the brain homoeostasis and support metabolism (Giaume et al., 2007). With the progression of AD, the function of the astrocytes is gradually lost, and some toxic neurotransmitters such as glutamate are released continuously, leading to the death of the surrounding neurons (Simpson et al., 2010). The Aβ plaques also disrupt the gliotransmission system by enhancing the calcium signal pathway (Lee et al., 2014). In addition, Aβ has been found to interact with several erythropoietin acceptors such as nicotinic receptors (a7-nAChRs), purinergic receptor P2Y1, and the glutamate metabotropic receptor mGluR5 (Delekate et al., 2014; Lee et al., 2014; Ronco et
The aberrant aggregated Aβ plaques induce the production of various proinflammatory mediators, including interleukin (IL)-1β, IL-6, tumor necrosis factor (TNF)-α, and reactive oxygen species (ROS) that lead to neuroinflammation and neuron death (Heneka et al., 2015a; 2015b; Flores et al., 2018). The selective inhibition of the chemokine receptor CX3CR1 in the brain can modulate the phagocytosis of microglia and the degradation of Aβ plaques (Liu et al., 2010). Plaque-associated microglia express known myeloid markers shared among macrophage progeny, microglia, and peripheral monocytes, including CD45, Iba1, and CD11b (Bennett et al., 2018). TMEM119 is another specific and stable cell-surface marker of human microglia that could be a possible therapeutic target (Bennett et al., 2016). Hence, activating the degradation of Aβ plaques by the microglia could be a way to manage AD.

Over the last few decades, the therapeutic strategies for AD are based on the “amyloid hypothesis” and researchers spent immense efforts in reducing the levels of Aβ (Cline et al., 2018). Some strategies for AD treatment aim to consolidate the clearance of Aβ plaque and elimination of neuroinflammation reactions (Lemere, 2013), and immunotherapy against Aβ and phosphorylated tau (p-Tau) has been suggested for more than 20 years. Pre-clinical studies have shown some efficacy of vaccines and active immunotherapies against Aβ and p-Tau, but the translation to humans proved ineffective and with serious safety issues (Song et al., 2020). Among others, a vaccine against Aβ1-42 (Elan Pharmaceuticals, CA, USA) could remove amyloid plaques and improve perceptive function in transgenic animal models and AD patients (Janus et al., 2000; Velas et al., 2009), but the clinical trial of the Aβ1-42 vaccine was suspended because of severe side effects like acute meningoencephalitis and cerebral hemorrhage (Rosenberg, 2005).

The aim of this study was to investigate Aβ plaques and changes of astroglia and microglia in mice injected with a new vaccine based on Aβ3-10 as the antigen. The cognitive and behavioral abilities of vaccinated mice were also observed. Due to the molecular and structural feature of the Aβ3-10 peptide, a carrier protein keyhole limpet hemocyanin (KLH), a highly immunogenic protein macromolecule, was synthesized with the Aβ3-10 peptide into an Aβ3-10 polypeptide vaccine (Aβ3-10-KLH). This new vaccine has a smaller fragment and has enhanced immunogenicity due to the coupling of KLH. It can effectively increase the concentration of anti-Aβ antibodies in experimental mice and reduce the deposition of Aβ in the brain. The immune response is mainly a Th2 type inflammatory reaction, thereby avoiding the side effects caused by Th1 type inflammatory reaction. Therefore, this new vaccine could solve the problem presented in the previous vaccine, such as ineffective and serious side effects, and may provide a better understanding of the mechanisms of AD and its treatment.

METHODS

Experimental design

This research was an experimental study which the AD mouse model (APPswe/PS1dE9 double transgenic mice) was used as the study object. This study was done to explore the preventive treatment of vaccines to transgenic mice and further explore the influence on Aβ plaques and glial cells in the cortex. Initially, the mice were subjected to 5 times immunotherapy with Aβ3-10-KLH and Aβ1-42 peptide vaccines at the age of 2.5, 3, 4, 5, 6 months. Then, the effects of the two vaccines on Aβ plaque deposition, astrocyte and microglia expression in the brain of mice, and their relationship with each other were explored further at the age of 10 months. Afterward, the vaccine’s effect on the inflammatory response in the brain of mice was explored by detecting the inflammatory factors IL-1β and TNF-α.

Vaccine synthesis

The Aβ3-10-KLH vaccine was prepared by coupling the sulfydryl group of cysteine (Cys) with KLH. The amino acid sequence of Aβ3-10 was H-Glu-Phe-Arg-His-Asp-Ser-Gly-Tyr-COOH. A Cys was added to the C-terminal of Aβ3-10 to couple with KLH. According to its amino acid sequence, the peptide (EFRHDSGYC) was synthesized by solid-phase synthesis from C-terminal to N-terminal. The peptide was purified by high-performance liquid chromatography with purity >95%. The relative molecular weight was 1113.17 by mass spectrometry. The above synthesis process was completed by Kingston Technology Co., Ltd. (Nanjing, China). The synthetic human Aβ1-42 peptide was obtained from AnaSpec Inc. (Fremont, CA, USA).

Animals

Eighteen 2.5-month-old APP/PS1 mice (half male and half female) with the genetic background B6C3-Tg (APPswe/PSEN1dE9) were obtained from the Guangdong Medical Laboratory Animal Center. These transgenic mice typically develop Aβ plaques at approximately 3 months (Zhong et al., 2014). Six age-matched
C57BL/6 mice (three males and three females) were used as control. All mice were kept at the China Medical University Laboratory Animal Center at 23±2°C, with humidity 50%±10%, and under a 12-h light/dark cycle. All the experiments were performed in accordance with National Institutes of Health (NIH; Bethesda, MD, USA) guidelines on the use of laboratory animals and approved by the Animal Ethics Committee of China Medical University (approval No. 103-316) on April 2, 2016.

**Immunization protocol**

The APP/PS1 mice were randomized to the Aβ3-10-KLH, Aβ1-42, and PBS groups (n=6/group). Six 2.5-month C57BL/6 wild type mice were used as the control group. The Aβ3-10-KLH and Aβ1-42 peptides were dissolved in PBS to a final concentration of 2 mg/ml and then emulsified 1:1 (v/v) with Freund’s complete adjuvant (Sigma, St. Louis, MO, USA) for the first inoculation and emulsified 1:1 (v/v) with Freund’s incomplete adjuvant (Sigma, St. Louis, MO, USA) for the next vaccinations. The mice in the Aβ3-10-KLH and Aβ1-42 groups were hypodermically injected with 100 μg of the peptide, and the mice in the PBS cluster and control cluster were injected with 100 μl of PBS. The immunization was performed five times (at 2.5, 3, 4, 5, and 6 months). After immunization, the mice were kept at the Experimental Animal Center of China Medical University until they were 10 months old. The animal experiments were approved by the Animal Ethics Committee of China Medical University and performed according to the guidelines of the Animal Care and Use Committee of China Medical University.

**Morris water maze test**

The spatial learning and memory abilities of the APP/PS1 transgenic mice and WT mice were detected by the Morris water maze test at the age of 10 months. In this experiment, the Morris water maze test system (Huaibei Zhenghua Biologic Apparatus Facilities Co., Ltd., Huaibei, China) was used. It consists of a circular pool with a diameter of 100 cm and a height of 40 cm. The inner wall of the pool was white, the water depth was 30 cm, and the water temperature was maintained at 22±2°C. In the room, the light was constant, and there was no direct light on the pool. The pool was divided into four quadrants by four equidistant points on the pool wall. In the target quadrant (set as the third quadrant), there was a round black platform with a diameter of 9 cm and a height of 28 cm, which was 2 cm below the water surface. During the experiment, the pool and the surrounding environment remained unchanged.

To evaluate the spatial learning ability of mice, the hidden platform positioning experiment was applied. The classic Morris water maze test was used for 5 consecutive days. The platform was set in the third quadrant, and the opposite side was the first quadrant. The quadrant setting sequence was clockwise. Before the experiment, the mice were placed on the platform to adapt for 20 s, and then they were placed into the first quadrant. The recording was terminated after the mice boarded the platform again for 5 s. The longest recording time was 60 s. If the mice could not get on the platform within 60 s, they would be guided to board the platform to adapt for 10 s. The mice were dried and put into the cage after the test. The test was carried out from the four quadrants sequentially for 5 days. The average latencies of the four quadrants per day were recorded.

To evaluate the spatial memory ability of the mice, the space search test was performed on the sixth day. The environment and water temperature were the same as the positioning navigation test. The platform under the water was removed, and then the mice were placed into the first quadrant. The times of crossing the platform in the third quadrant (target quadrant) were recorded.

**Tissue preparation**

After the Morris water maze test, the mice were anesthetized intraperitoneally deeply with 2% sodium pentobarbital, and the heart was perfused. The thoracic cavity was cut open to expose the cardiopulmonary region fully. The perfusion needle was quickly inserted into the apex of the heart to the ascending part of the aorta. At the same time, the right atrial appendage was cut to make the perfusate flow out after circulation until the limbs and liver became white and the perfusate fluid was clear. The skull was exposed and cut from the middle and both sides. The skull was gently lifted off with tweezers to expose the brain tissue. The left brain was fixed in 4% paraformaldehyde PBS solution, and the right brain was stored in a sterilized centrifuge tube at -80°C.

**Detection of IL-1β and TNF-α levels in APP/PS1 transgenic mice by ELISA**

The frozen brain tissue stored at -80°C was taken out and thawed on ice. The brain tissue was cut into
small pieces with sterile ophthalmic scissors, and the tissue lysate solution (50 mM Tris buffer + 250 mM NaCl + 5 mM ethylenediaminetetraacetic acid + 2 mM Na3VO4 + 1 mM NaF + 20 mM Na4P2O7 + 0.02% NaN3, and pH 7.4) was added. An electric homogenizer was used to grind the brain tissue (10 s/time, 30-s interval, 3-5 times) until there was no obvious solid tissue in the solution, and it was kept at 4°C for 30 min. The homogenate was centrifuged at 4°C at 3000 rpm for 15 min, and the supernatant was kept for enzyme-linked immunosorbent assay (ELISA).

ELISA was performed using the mouse IL-1β ELISA kit (ab100704, Abcam, Cambridge, UK) and TNF-α ELISA Kit (ab100747, Abcam, Cambridge, UK). Both the ELISA kits were removed 20 min earlier from the refrigerator. A blank hole was added and specimen diluent; remaining concentrations were added in the appropriate hole (100 μl/hole), incubated at room temperature for 2.5 h. Prepared 20 min in advance of biotinylated antibody working solution and then washed four times. Blank hole added with biotinylated antibody diluent added remaining blank hole with biotinylated antibody working solution (100 μl/hole). A new cover plate of plastic tapes was placed in reaction holes and incubated at room temperature for 60 min, prepared 20 min in advance of conjugate working solution, protected from light at room temperature, and washed five times. Blank hole added with conjugate diluent added remaining with a conjugate working solution (100 μl/hole). A new cover plate of plastic tapes was placed in reaction holes and incubated at 36°C for 45 min. Powered on the microplate for preheating equipment and to set up testing procedures. Washed five times and joined the chromogenic substrate 100 μl/hole, incubated at 36°C for 30 min without the presence of light. Adding stop solution 100 μl/hole, and the plates were read at 450 nm immediately after mixing (Karim et al., 2019; Wang et al., 2020).

**Statistical analysis**

The data are presented as means ± standard deviations (SD) and analyzed using ANOVA with Tukey’s post hoc test. SPSS 23.0 (IBM, Armonk, NY, USA) was used for analysis. Two-sided P-values <0.05 were considered statistically significant.

**RESULTS**

Aβ3-10-KLH immunization improves the behavioral performance of the mice

To determine the effect of the Aβ3-10-KLH vaccine on the cognitive and behavioral abilities of mice, the Morris water maze test was carried out of the mice in each group at the age of 10 months after five vaccine injections. As shown in Fig. 1, in the visual platform training, there were no significant differences in the latency of the Aβ3-10-KLH vaccine, Aβ1-42 peptide, PBS control, and wild type control groups (P>0.05), indicating that the Aβ3-10-KLH and Aβ1-42 vaccines did not affect the visual and motor functions of the mice. In the hidden platform training, the latency of the Aβ3-10-KLH and Aβ1-42 vaccine groups was significantly shorter than that of the PBS control group on the 3rd to 5th day (**P<0.001), but there were no significant differences between the Aβ3-10-KLH and Aβ1-42 vaccine groups (P>0.05). In the space exploration experiment, compared with the PBS group, the Aβ3-10-KLH and Aβ1-42 vaccine groups significantly increased, and the times of crossing the platform significantly increased (**P<0.001). There were no significant differences between the Aβ3-10-KLH and Aβ1-42 vaccine groups (P>0.05). Therefore, the Morris water maze results showed that both the Aβ3-10-KLH and Aβ1-42 vaccines could significantly improve the cognitive function of APP/PS1 transgenic mice.
Aβ3-10-KLH immunization reduces Aβ plaques in the cortex

We then evaluated whether the effect of Aβ3-10-KLH and Aβ1-42 vaccines on cognitive function was related to Aβ deposition. As showed in Fig. 2, compared with PBS control mice, Aβ3-10-KLH and Aβ1-42 significantly reduced Aβ deposition in the cerebral cortex, as detected by immunofluorescence. Significant Aβ deposition was not observed in wild-type control mice. Compared with the PBS group, Aβ3-10-KLH and Aβ1-42 inoculation reduced the total fluorescence density of 6E10+ Aβ plaques in the cortex (**P<0.001), respectively. Aβ3-10-KLH and Aβ1-42 inoculated mice showed a similar decrease in 6E10+ Aβ load (P>0.05).

Aβ3-10-KLH or Aβ1-42 alleviates the activation of astrocytes

To test the effect of Aβ3-10-KLH or Aβ1-42 on astrocytes, we detected its hallmark protein GFAP expression with immunohistochemistry. Here we demonstrated that GFAP+ astrocytes in experimental clusters were all activated at various degrees compared with the control group. The GFAP+ astrocytes in the PBS group were significantly higher compared with the Aβ3-10-KLH and Aβ1-42 mice (Fig. 3A). The total fluorescence density analysis confirmed that GFAP+ astrocytes were significantly reduced (**P<0.001) in the cortex of the Aβ3-10-KLH and Aβ1-42 mice respectively compared with the PBS mice (Fig. 3B). Furthermore, double-immunofluorescence staining was used to detect the relationship between activated astrocytes and Aβ plaque. Fig. 3C showed that in the Aβ3-10-KLH and Aβ1-42 groups, the astrocytes (GFAP in red) around the Aβ plaques (6E10 in green) were relatively increased. In the PBS group, the area of Aβ plaque was higher, while interestingly, the astrocytes around the Aβ plaque were lower. In the control group (WT), there was almost no deposition of Aβ plaques.

Aβ3-10-KLH or Aβ1-42 vaccination depresses microglial activation in the cortex

On the other hand, considering the important role of microglia in uptake and clearance of different forms of Aβ, we checked the effect of the vaccination on microglia. Here we showed that TMEM119+ microglia of the Aβ3-10-KLH and Aβ1-42 mice were slightly increased compared with the wild type mice, which reached highest in the PBS group (Fig. 4A). The fluorescence density analysis confirmed that the TMEM119+ microglia were significantly fewer in the cortex of the Aβ3-10-KLH and Aβ1-42 groups (**P<0.001) than that of the PBS group (Fig. 4B). And there were no significant differences between the Aβ3-10-KLH and Aβ1-42 groups.
Aβ3-10-KLH or Aβ1-42 vaccination reduces the contents of IL-1β and TNF-α in the brain of the mice

In the CNS, activated astrocytes and microglia are the main sources of inflammatory factors such as cytokines, chemokines, and neurotransmitters. The released cytokines, especially IL-1β and TNF-α, are the main effectors of neuroinflammatory signals, affecting the neurophysiological mechanism of cognition and memory (Gemma et al., 2007). Cytokines can establish a feedback loop to activate more astrocytes and microglia, leading to further inflammatory molecule production that will also recruit monocytes and lymphocytes, and other cells to cross the blood-brain barrier (BBB), thereby enhancing the inflammatory response of the CNS (Das et al., 2008). Therefore, we used Aβ3-10-KLH and Aβ1-42 vaccine to detect IL-1β and TNF-α levels in the brain after immunotherapy to show the inflammatory response in the after-treatment and further to verify the effect of active immunotherapy on inflammation.

The contents of IL-1β and TNF-α detected by ELISA in the brain of transgenic mice treated with the Aβ3-10-KLH or Aβ1-42 vaccine were decreased significantly than the PBS group. As shown in Fig. 5A and 5B, the contents of IL-1β and TNF-α in the brain of transgenic mice immunized with Aβ3-10-KLH vaccine and Aβ1-42 vaccine group were significantly reduced (***P<0.001) in comparison with the PBS group. There were no significant differences in the content of IL-1β and TNF-α in the brain of the Aβ3-10-KLH and Aβ1-42 vaccine groups (P>0.05). Taken together, the reduction of proinflammatory mediators IL-1β and TNF-α may be one of Aβ3-10-KLH and Aβ1-42 vaccines mechanisms in decreasing aberrant aggregated Aβ plaques.

**DISCUSSION**

The pathogenesis of AD is complex which is characterized by a progressive loss of neurons and involves Aβ plaques formation, activation of astrocytes and microglia (Guo et al., 2020; Tiwari et al., 2019). Vaccines and active immunotherapy are being studied against AD (Bittar et al., 2018; Song et al., 2020). The aim of this study was to investigate Aβ plaques and changes of astroglia and microglia in mice injected with a new
vaccine based on Aβ3-10 as the antigen. The results strongly suggest that early immunotherapy with an Aβ vaccine reduces the activation of glial cells and deposition of Aβ plaque in the brain of transgenic mice.

Although there are many theories on the pathophysiological process of AD (Guo et al., 2020; Tiwari et al., 2019), the amyloid hypothesis is still the main accepted theory (Cline et al., 2018). The amyloid hypothesis states that the secretion and accumulation of Aβ lead to the formation of Aβ plaques, which contribute to molecular and cellular alterations through pathological changes. (Selkoe and Hardy, 2016). Currently, the US Food and Drug Administration has approved only five drugs for clinical use (Yiannopoulou and Papageorgiou, 2020), but unfortunately, none of these drugs can stop the development of AD and can only improve the clinical symptoms of AD (Liu et al., 2010; Lyman et al., 2014) partially. The AN-1792 clinical trial of anti-Aβ immunotherapy, significantly improved the clinical manifestations, but it was halted due to significant adverse events (Patton et al., 2006). One of our previous study showed that Aβ3-10-KLH vaccination induces serum anti-Aβ antibodies and improves the memory function in transgenic mice, and induced Th2-polarized im-

![Fig. 3. Aβ3-10-KLH and Aβ1-42 alleviate the activation of astrocytes. (A) The activation of the astrocytes in the cortex of the Aβ3-10-KLH and Aβ1-42 mice was higher in control group (WT) and lower than in the PBS group. Scale bar=50 μm. (B) The total fluorescence density of GFAP+ astrocytes in Aβ3-10-KLH and Aβ1-42 group were lower than PBS group (**p<0.001). (C) Double-immunofluorescence staining showing that the Aβ plaques (green) in the Aβ3-10-KLH and Aβ1-42 mice were smaller than in the PBS mice, while the astrocytes (red) surrounding the Aβ plaques were increased. Scale bar=25 μm.](image-url)
immune responses, which suggested that it could effectively protect the transgenic AD mice without severe adverse events such as meningoencephalitis induced by Th1 immune responses (Ding et al., 2016). Furthermore, it is also suggested that Aβ3-10-KLH vaccination could significantly improve behavioral outcomes due to high antibody production and cognitive function improvement, (Wang et al., 2020) also revealed that after vaccine injection, mice produced high levels of Aβ antibody, and cognitive function was significantly improved, which resembles our study findings. In this study, both Aβ3-10-KLH and Aβ1-42 vaccination could reduce Aβ deposition in APP/PS1 transgenic mice. This study strongly suggests that the use of the Aβ3-10-KLH vaccine could be a treatment method for AD. Nevertheless, additional studies are necessary to ensure the higher safety of Aβ3-10-KLH vaccination compared with Aβ1-42 vaccination.

The astrocytes play the role of supporting and separating nerve cells and are involved in the BBB and the regulation of synaptic activity. They also produce and secrete some neurotransmitters and express some neurotransmitter receptors (Iglesias et al., 2017; Vasile et al., 2017). In AD, reactive astrocytes also influence the clearance and deposition of Aβ plaques through the β-binding receptors CD36 and CD47 (Acosta et al., 2017). In addition, astrocytic dysfunction enhances the deterioration of neurons (Acosta et al., 2017). Astrocytes also express some metalloendopeptidases and matrix metalloproteinases, including NEP, IDE, MMP-2, and MMP-9, which promote the degradation of Aβ species in APP/PS1 transgenic rats (Yan et al., 2006; Mulder et al., 2012; Ries and Sastre, 2016). On the other hand, activated astrocytes produce lots of α1-antichymotrypsin in controlling Aβ degradation and triggering hyperphosphorylation of tau (Avila-Munoz and Arias, 2014). The reactive astrocytes may help remove dysfunctional synapses or synaptic fragments and enhance the inflammatory effects of damaged neurons (Gomez-Arboledas et al., 2018). In this study, Aβ3-10-KLH and Aβ1-42 immunization significantly alleviated astrogliosis in APP/PS1 transgenic mice, but, interestingly, it was observed that the astrocytes around Aβ plaques showed apoptosis in the PBS group. A possible reason might be that Aβ plaques are alleviated after immunotherapy. Activated astrocytes participated in the process of
Aβ plaque clearance, but astrocytes around severe Aβ plaques were gradually necrotic. It suggests that Aβ plaques have obvious toxicity on astrocytes and that the elimination of Aβ plaques would be essential for the maintenance of astrocytes homeostasis.

In the CNS, the microglia are the available and intrinsic phagocytes that take part in the uptake and clearance of different forms of Aβ (Lee and Landreth, 2010; Villacampa and Heneka, 2020). Some studies showed that the accumulation and deposits of Aβ induced the mobilization of an innate immune response, then caused the pathogenic cascades of AD, suggesting the critical link between the immune system (especially microglia) and Aβ plaques (Heneka et al., 2015a; 2015b; Weitz and Town, 2012). With the formation of Aβ plaques and NTFs, the brain of AD patients presents an obvious chronic neuroinflammatory response characterized by increased reactive microglia and increased levels of proinflammatory cytokines (Scheltens et al., 2016). Furthermore, free irons also participate in increasing oxidative stress in microglia, causing a series of biochemical changes in the CNS (Chiziane et al., 2018), but whether the activation of microglia is beneficial or harmful to the neurons is still obscure (Swanson et al., 2020; Villacampa and Heneka, 2020). Recent studies suggest that different phenotypes of microglia could have different effects on AD progression (Cunningham, 2013; Lyman et al., 2014). Activated microglia not only strongly induces the activation of astrocytes by secreting neurotoxins and various complement components but also promotes synaptic degeneration and neuronal death together with active astrocytes (Liddelow et al., 2017). In this study, the involvement of the microglia in the AD-associated changes was assessed after Aβ3-10-KLH and Aβ1-42 vaccination. There was a general decrease of the TMEM119 labeling intensity in vaccinated APP/PS1 mice compared with the control group. This might suggest that reducing the formation of Aβ plaques through immunotherapy reduced the activation of microglia cells in the brain at the early stage of AD. Nevertheless, because the response of microglia in mouse models seems more intense than in humans (Navarro et al., 2018), the effect of immunotherapy on microglia and neuroinflammation in late AD brains needs further study.

Although immunotherapy has been observed to have a good effect in transgenic animals, the limitation of the study is due to the small sample size. Adverse effects and possible mouse death were not observed. Whether the results can be translated to humans is unknown. Therefore, more studies are needed to verify their effectiveness in clinical research.

CONCLUSION

The application of Aβ3-10-KLH and Aβ1-42 vaccines in APP/PS1 transgenic mice reduced the formation of
Aβ plaques and decreased astrocyte and microglia activation. This study suggests a new and safe measure for treating AD. Immunotherapy offers promising therapeutics that could prevent the development of amyloid pathologies and cognitive decline.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China, No. 81870819 (to YPC). The funding body played no role in the study design, in the collection, analysis, and interpretation of data, in the writing of the paper, or in the decision to submit the paper for publication.

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