

## **Circulating Oxysterols in Alzheimer's disease: A Systematic Review and Meta-analysis**

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## Abstract

Despite decades of research, the cause and series of events underlying the advancement of Alzheimer's disease (AD) has not yet been established. Lipids and especially cholesterol levels have been proposed to be implicated in AD. Several studies have been undertaken and many ongoing in different directions looking at the importance of circulating cholesterol and oxidised cholesterol in Alzheimer's disease with inconsistent methods and results. This meta-analysis aims to systematically analyse available data describing the involvement of oxidised cholesterol in Mild cognitive impairment (MCI) and Alzheimer's disease (AD). We conducted a systematic literature search of 6 databases MEDLINE (PubMed), BIOSIS (Web of Science), EMBASE (Elsevier), PsycNET, Scopus and Cochrane library for studies measuring oxysterols (24-hydroxycholesterol (24OHC); 26-hydroxycholesterol (26OHC) and 7-oxysterols) in serum or plasma from MCI / AD patients compared to age and gender matched cognitively normal controls. Data was analysed using the inverse variance and standard mean difference with random effect analysis model at 95% confidence interval for association between oxysterols and MCI / AD in Review Manager (RevMan) software version 5.4.1. 175 studies between January 2000 and April 2022 were identified by 2 independent researchers out of which 14 met the inclusion criteria and were analysed with a total of 957 controls, 469 MCI cases and 509 AD cases. The standard mean differences between MCI / AD participants and controls did not show any difference in the oxysterol levels except for 26OHC level which were higher in AD but not statistically significant.

**Keywords:** Oxysterols, Alzheimer's disease, serum, plasma, meta-analysis

## Introduction

Alzheimer's disease (AD) is the most common type of dementia where affected individuals suffer progressive cognitive decline and cognitive impairment. It has been estimated that AD sufferers worldwide will reach 81 million by 2040 with most of the sufferers being old-age adults [Ferri et al 2005]. Over 9.9 million new cases of dementia are predicted each year worldwide and is forecast to be the major societal health challenge of the 21st century [World Alzheimer Report 2001]. It is widely recognised that AD has an extended preclinical stage before presenting cognitive decline and neuropathological changes in middle to older adults. Therefore, it is vital to understand preclinical biomarkers and underlying mechanisms of its progression to predict and apply into successful prevention trials.

The discovery of the genetic association of apolipoprotein E (ApoE)  $\epsilon$ 4 allele with sporadic and familial late-onset AD suggested the possibility of dysfunction in the lipid metabolism and lipid transport in the brains of AD subjects [Minagawa et al 2009]. ApoE is produced by astrocytes and glial cells, and it is a primary transporter of cholesterol involving lipoprotein particles in the brain. The key role of ApoE is to redistribute lipids through receptor mediated uptake for neurite growth [Minagawa et al 2009]. In addition to the identification of genetic risk factors for vascular dementia and familial and sporadic AD, multiple lines of evidence suggested a strong relationship between lipid homeostasis and vascular changes in the brain of AD subjects [Vaya & Schipper 2007, Papassotiropoulos et al 2000, Mutemberezi et al 2016]. These includes epidemiologic studies that links environmental vascular risk factors to dementia; evidence from stroke studies [Leduc et al 2010, Hughes et al 2013], interaction with amyloid deposition [Loera-Valencia et al 2019] and Tau phosphorylation [Papassotiropoulos et al 2003] in a cholesterol-rich environment, microvascular abnormalities in AD and changes to blood-brain barrier functions in hypercholesterolemic subjects [Loera-Valencia et al 2019]. Lipids are at the core of AD pathology due to their involvement in various cellular functions in the brain including the energy balance, myelination, membrane remodelling, signalling cascades, inflammation and resolution of inflammation. Based on these observations the relationship between lipids, especially cholesterol and AD has been extensively investigated in epidemiological studies in the past decade [Ferri et al 2005, Dias et al 2015, Barnes et al 2011]. Previous meta-analysis compared levels of lipids or lipoproteins in the blood, which include low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), total cholesterol (TC) and triglycerides (TG) [Sáiz-Vazquez et al 2020]. This meta-analysis showed that there is an association between the effect of cholesterol in AD where LDL-C has a significant impact on the development of AD pathologies.

Oxidative stress and oxidative modifications to macromolecules is one of the earliest events in AD pathology [Bai et al 2022, Nunomura et al 2001]. Among the lipid oxidation observed in AD, cholesterol can be oxidised via non-enzymatic reactions and enzymatic oxidation, thus resulting in oxysterols. While peripheral cholesterol metabolism is kept independent to the brain, there are evidence to suggest that oxysterols can transfer to and from the brain via blood-brain barrier. Polar oxysterols that can proficiently pass the lipophilic blood brain barrier have obtained substantial recognition as a potential connection between serum cholesterol, modified brain cholesterol metabolism and brain pathophysiology [Hughes et al 2013, Dias et al 2014, Iuliano et al 2011]. Non-enzymatic oxidation to cholesterol can occur through reactions initiated by free radical species arising from the superoxide, hydrogen peroxide, hydroxyl radical system. These reactions oxidise the 7<sup>th</sup> position of the cholesterol main ring deriving 7-oxysterols (7 $\alpha$ -hydroxycholesterol, 7 $\beta$ -hydroxycholesterol and 7-ketocholesterol) and epoxy cholesterols [Iuliano et al 2011]. The susceptibility of cholesterol to non-enzymatic oxidation and increased oxidative stress observed in AD has raised considerable interest in the function of these oxysterols as biological effectors and potential biomarkers in AD [Mahalakshmi et al 2021].

Conversion of excess brain cholesterol to 24-hydroxycholesterol (24OHC) by the neuron-specific enzyme CYP46A1 is one of the main routes by which excess cholesterol is removed from the brain [Gamba et al 2021]. Cholesterol is also enzymatically converted to 26-hydroxycholesterol (26OHC, also identified as 27-hydroxycholesterol) via 27-hydroxylase (CYP27A1) in neurones and other cell types. The 26OHC is produced mainly by peripheral tissues, although a small amount is also generated by the brain. Brain derived 26OHC is then transferred to the blood and catabolized toward bile acids in the liver by oxysterol 7 $\alpha$ -hydroxylase (CYP7B1). As the most abundant oxysterol in peripheral circulation, 26OHC is found to be associated with the cholesterol content in atherosclerotic lesions and the severity of coronary artery disease [Vaya et al 2001]. In vivo studies demonstrated that mutations in several HDL genes could redistribute 26OHC levels in HDL and plasma as well as specific changes in the esterification of 26OHC [Karuna et al 2011]. Administration of 26OHC through the tail vein negatively affected cognitive function and cholesterol metabolism in rats [Zhang et al 2015]. These observations led to later case-control studies that demonstrated a strong association between high plasma levels of 26OHC and mild cognitive impairment [Liu et al 2016]. These observations suggest that oxysterols could act as a link between hypercholesterolemia and AD. Considering this background, the aim of this study is to provide

an updated systematic review and meta-analysis of available data on oxysterols and the risk related to the development of AD.

## Methods

### *Data acquisition and criteria*

This review included a search of 6 databases MEDLINE (PubMed), BIOSIS (Web of Science), EMBASE (Elsevier), PsycNET, Scopus and Cochrane for studies measuring oxysterols (24 hydroxycholesterol; 26 hydroxycholesterol / 27 hydroxycholesterol and 7-oxysterols) in serum or plasma from MCI / AD patients compared to age and gender matched cognitively normal controls published between January 2000 and April 2022. The Boolean terms used were [plasma OR serum OR blood] AND [oxysterols] AND [Alzheimer's disease] NOT review. Authors performed the initial searches and eliminated duplicates and articles that satisfied the inclusion criteria were selected independently and checked for full text availability. *Figure 1* summarises the inclusion and exclusion criteria.

### *Study Selection*

Inclusion criteria are:

1. Studies on human subject, published between January 2000 and April 2022
2. Case-control study design that reported quantitative measurement of total cholesterol and oxysterols (24OHC, 26OHC and 7-oxysterols) in serum or plasma of MCI / AD patients and age and gender matched cognitively normal controls.

Studies that provide data on at least one of the classes of lipids to be analysed were used and there was no limitation based on quantification methodology.

Exclusion criteria are:

1. Lack of control groups
2. Other forms of dementia and not AD
3. Intervention studies
4. Review papers, letters, editorials, conference papers or other non-original research articles.

Studies in any of the listed categories were excluded from the meta-analysis.

### *Data extraction and assessment*

Two independent reviewers performed the search and collected the data. The mean, standard deviation, and standard error as well as the adjusted oxysterol levels were extracted. We explored the year, country of study design, use of quality control, criteria for AD diagnosis, mean age, gender, type of sample, assay method, laboratory kit used, collection process, sample storage, sample preparation, and blinding of personnel were assessed for each study. Variables extracted from each of the 14 studies shortlisted for meta-analysis are shown in *Table 1* and include: mean and standard deviation (SD). We used the formula  $SD = SE \cdot \sqrt{N}$  to calculate SD for data reported as standard error (SE), where N is the number of participants.

### *Data Analysis*

Statistical analyses were performed using the Review manager (RevMan) version 5.4.1 (provided by [www.cochrane.org](http://www.cochrane.org)). The meta-analysis compared the mean differences and standard deviations within the study groups using inverse variance for the continuous data. Chi-square test was used to investigate heterogeneity within the studies, and sensitivity analysis was used to identify the source of heterogeneity. A random effects model was used for analysis with heterogeneity ( $P \leq 0.1$ ,  $I^2 \geq 50\%$ ). We used the standardised mean difference (SMD), and 95% CI were calculated to analyse statistical data effectiveness for the continuous data. The difference was statistically significant when  $P < 0.05$ .

We categorised the studies into 3 groups for separate meta-analyses: i) Total 24OHC composition of plasma/serum in studies comparing AD or MCI to cognitively normal individuals. ii) 26OHC composition of plasma/serum in studies comparing AD or MCI to cognitively normal individuals. iii) 7-oxysterol composition of plasma/serum in studies comparing AD or MCI to cognitively normal individuals. We performed a total of 1935 meta-analyses (957 control vs 469 MCI and 509 AD). Oxysterol summary table, including all units, and sources are shown in *Table 1*. The meta-analysis overall effect results were accepted as statistically significantly different if they have  $p \leq 0.05$ .

## Results

### *Literature search results*

The flow diagram of the literature searches and study selection is shown in *Figure 1*. Overall, 175 studies between January 2000 and April 2022 were identified by 2 independent researchers. Finally, 14 observational studies met the inclusion criteria and were included in the meta-analysis. Sample size ranged from 10 - 140 subjects and analysed with a total of 957 controls, 469 MCI and 509 AD cases. Populations in the included studies were from Pittsburgh (USA), Germany, Spain, Tunisia, China, Brazil, India and Sweden. Data of the included studies are summarised in *Table 1*. The full list of plasma/serum levels of oxysterols reported in each paper are in the Forest plot summary tables. Only studies reporting mild cognitive impairment (MCI) and dementia of the Alzheimer's type were used for meta-analysis. Highly specific mass spectrometric approaches (either LCMS or GCMS) were used for the analysis of oxysterols in all the studies except for Roy et al. 2019 who used sandwich ELISA.

**Figure 1.** Flow diagram of the study selection process for studies included in the meta-analysis. All included studies were controlled trials.

**Table 1:** Quantitative data and characteristics of the selected studies. Summary details of the 14 published studies included in the meta-analyses.

### *Studies on oxysterols and MCI*

To understand the relationship between circulating 24OHC, 26OHC and 7-oxysterols in disease progression, first we investigated data from subjects with MCI (*Figure 2*). The data used in the meta-analysis were calculated and converted from the original data. Among seven studies included in this analysis, no change was reported for 24OHC levels in four studies [Liu et al 2016, Hughes et al 2012, Iuliano et al 2010]. While Hughes et al. (2012) and Popp et al. (2012) reported increased levels of circulating 24OHC in MCI, Mateos et al. (2011) reported decreased levels. For 26OHC, Hughes et al. (2012) and Popp et al. (2012) reported decreased circulating levels in MCI but Liu et al. (2016) and Zuliani et al. (2011) reported 26OHC is higher in MCI plasma.

Overall, 24OHC showed no difference between control and MCI; the standardised mean difference was 0.07 (95% CI: -0.12 to 0.26,  $P = 0.47$  *Figure 2*). No statistical heterogeneity was found ( $\chi^2 = 7.82$ ,  $P = 0.25$ ,  $I^2 = 23\%$ ). Likewise, 26OHC showed no difference between control and MCI; the standardised mean difference was 0.20 (95% CI: -0.41 to 0.81,  $P = 0.53$  *Figure 2*). However statistical heterogeneity was found ( $\chi^2 = 108.48$ ,  $P < 0.00001$ ,  $I^2 = 94\%$ ). Subgroup analysis (not shown) did not show statistical significance for 24OHC and 26OHC either. 7-oxysterols showed no difference between control and MCI; the standardised mean difference was 0.09 (95% CI: -0.16 to 0.34,  $P = 0.49$  *Figure 2*). No statistical heterogeneity was found ( $\chi^2 = 0.47$ ,  $P = 0.49$ ,  $I^2 = 0\%$ ).

The overall effect of the oxysterols analysed between control and MCI were not significant.

**Figure 2. Forest plots of concentration of oxysterols in plasma/ serum in MCI vs Control meta-analyses.** Results from the meta-analysis of 14 studies using random-effect model did not show significant difference for oxysterols (24OHC, 26OHC and 7-oxysterols) tested in subjects with MCI compared to healthy controls.

### **Studies on oxysterols and AD**

To explore the relationship between circulating oxysterols levels and risk of AD, next we investigated data from subjects with AD (*Figure 2*). Data for 24OHC, 26OHC and 7-oxysterol levels were also inconsistent in literature. Out of 10 studies analysed for 24OHC, six studies reported high circulating levels [25, 28, 29, 32, 35, 36] and four studies reported low circulating levels [Costa et al 2018, Mateos et al 2011, Qureschie et al 2008, Roy et al 2019] in AD compared to control. For 26OHC, three studies reported high circulating levels [Iuliano et al 2010b, Popp et al 2013, Zarrouk et al 2020], two studies reported low levels [Hughes et al 2012, Mateos et al 2011] and one study reported no change [Costa et al 2018] compared to control. 7-oxysterol levels were reported as high in both studies but not statistically significant [Iuliano et al 2010b, Zarrouk et al 2020].

Overall, 24OHC showed no difference between control and AD; the standardised mean difference was -0.03 (95% CI: -0.58 to 0.52,  $P = 0.91$  *Figure 3*). However statistical heterogeneity was found ( $\chi^2 = 144.92$ ,  $P < 0.00001$ ,  $I^2 = 94\%$ ). 26OHC showed no difference between control and AD; the standardised mean difference was 0.07 (95% CI: -0.34 to 0.48,  $P = 0.73$  *Figure 3*). However statistical heterogeneity was found ( $\chi^2 = 24.09$ ,  $P = 0.0002$ ,  $I^2 = 79\%$ ) for 26OHC. 7-oxysterols showed no difference between control and AD; the standardised mean difference was 0.23 (95% CI: -0.11 to 0.56,  $P = 0.18$  *Fig.3*). No statistical heterogeneity was found ( $\chi^2 = 0.36$ ,  $P = 0.55$ ,  $I^2 = 0\%$ ).

The overall effect of the oxysterols analysed between control and AD were not significant.

**Figure 3. Forest plots of concentration of oxysterols in in Plasma/ Serum in AD vs Control meta-analyses.** Random-effect model did not show significant difference to oxysterols measured in AD patients compared to healthy controls.

### **Discussion**

Oxysterols, especially neuronal derived 24OHC and peripheral 26OHC has been of interest as biomarkers for neurodegeneration including AD. A large portion of the total 24OHC in the periphery is known to be produced in the brain [Björkhem et al 1998]. During brain cholesterol metabolism, 99% of brain derived 24OHC is estimated to enter into the plasma and excreted via liver [Lütjohann et al 1996], reflecting brain cholesterol metabolism. Plasma levels of



24OHC seems to be stable in healthy subjects regardless of the sex differences, but there are mixed results on circulating 24OHC levels in AD [Dzeletovic et al 1995]. Defective blood brain barrier permeability in AD has been suggested to increase permeability of many brain biomarkers into the circulation including oxysterols [Dias et al 2014]. To ascertain 24OHC as a possible biomarker for neurodegeneration, many previous studies investigated 24OHC levels in brain as well as in blood and the results have been reviewed before [Leoni et al 2013, Leoni et al 2013b, Leoni et al 2011]. Therefore, the aim of this study was to incorporate recent findings and to analyse available data to investigate any changes to circulating oxysterol levels in AD. This meta-analysis shows that circulating levels of 24OHC, 26OHC and 7-oxysterols are not changed between healthy subjects and patients with MCI or AD.

Some studies observed increased 24OHC at the early stage of the disease due to increased brain cholesterol turnover, but majority of the studies did not observe changes to circulating 24OHC levels in AD [Liu et al 2016, Hughes et al 2014, Iuliano et al 2010]. Lutjohann et al. (2000) reported significantly higher concentration of 24OHC in AD and non-Alzheimer demented patients compared to healthy controls and in depressed patients. Agreeing with this, Popp et al. reported increased 24OHC in circulation [Popp et al 2013]. In contrast, several studies reported decreased levels of 24OHC in AD and MCI [Roy et al 2019, Bretillon et al 2000, Kölsch et al 2004] and a correlation with severity of AD and decrease of 24OHC [Ruthirakuhan et al 2019]. Plasma 24OHC was also found significantly reduced in some other human neurodegenerative diseases such as Multiple Sclerosis (MS) [Teunissen et al 2003], and Huntington disease (HD) [Solomon et al 2009] [Leoni et al 2013]. Since AD progression is coupled with loss of 24-hydroxylase expressing neurons, brain 24OHC levels are found to be significantly lower than in healthy subjects [Testa et al 2016, Dias et al 2022]. The reduction of neuronal cell rich grey matter during neurodegeneration could be mirrored by a parallel reduction of peripheral 24OHC [Solomon et al 2009]. However, Solomon et al. described that 24OHC significantly related to brain volumes in the control group but not with MCI or AD groups despite the significant decrease in plasma 24OHC levels. Previous work found a differential expression of the CYP46 enzyme in glial cells in AD [Brown et al 2004]. Abnormal induction of the cholesterol-catabolic enzyme CYP46 in glial cells may act as a compensatory mechanism in neurodegeneration masking the direct correlation between brain volume and the evolution of the disease. It is also possible that the differences observed in circulating 24OHC may be due to individual variance to hepatic clearance rates of 24OHC. It was estimated that 24OHC is eliminated from the human circulation with the half-lives of 10-14 hours [Björkhem et al 1998]. However, there are no data available for differential clearance of 24OHC in AD patients. Another confounder to varied levels of 24OHC would be polymorphism

in 24-hydroxylase gene. Previous reports suggest that polymorphisms in CYP46A1 are associated with an increased load of A $\beta$  or earlier onset of AD [Papassotiropoulos et al 2003, Kölsch et al 2002].

Hughes et al. (2014) have shown that plasma oxysterol concentrations were higher amongst normal individuals who progressed onto developing MCI or AD by an 8 year follow up study. This study demonstrated that blood lipid levels were not associated with A $\beta$  status in the non-demented elderly group. However, higher levels of oxysterols and in particular, significantly greater ratios of 24OHC to 26OHC and cholesterol were related to A $\beta$  deposition between individuals with MCI. This might reflect alterations in cholesterol metabolism occurring early-on in the cognitive impairment process and may be indicative for individuals experiencing cognitive deterioration. However, it was uncertain whether all the subjects with MCI would progress onto AD or if 24OHC levels were directly associated with AD pathology. Roy et al. (2019) reported that serum 24OHC does not correlate with APOE4 genotype in AD subjects. Recently, Gamba et al. (2021) discussed the ambiguity of 24OHC levels related to AD pathogenesis and the controversial role it plays in the brain.

Enzymatically derived 26OHC is mainly produced in peripheral tissues and transported to the brain via BBB. This transport may be limited in healthy people due to intact BBB but could be increased during compromised BBB functions in AD. Therefore, multiple research studies have investigated the potential role of increased 26OHC in brain cell activity. Generally, 26OHC levels in the brain are about 10-fold less than that of 24OHC [Hughes et al 2013]. Even though the low abundant 26OHC might not severely influence the brain cholesterol metabolism, there are copious evidence to suggest its neuronal toxicity [Dias et al 2015, Gamba et al 2014]. At low concentrations, 26OHC induced neuronal cell oxidative stress and increased A $\beta$  production [Gamba et al 2014, Dias et al 2014]. Animal studies also indicated that 26OH levels alter synaptic potentiation and could lead to dysfunction of fine-tuned processing of information in hippocampal circuits resulting in cognitive impairment [Loera-Valencia et al 2021]. These studies confirmed neuronal toxicity exerted by 26OHC at high concentrations. Leoni et al. investigated the possibility of using 24OHC and 26OHC to inform differences between different conditions that affects neuronal damage (multiple sclerosis, AD, viral meningitis, chronic demyelinating polyneuropathies and subarachnoid haemorrhage) [Leoni et al 2004]. The study concluded no significant change to plasma levels of 24OHC and 26OHC, but neuronal damage and demyelination could increase oxysterol levels in cerebrospinal fluid (CSF) [Leoni et al 2004]. These studies clearly show that there is oxysterol involvement on neuronal cell damage in the brain but less likely that oxysterol levels would mirror this effect in the circulation. A meta-analysis to investigate 24OHC and 26OHC as

surrogate biomarkers in CSF demonstrated both 24OHC and 26OHC is increased in MCI and AD [Wang et al 2016]. Altered cholesterol metabolism and increased cholesterol levels in CSF during MCI [Mateos et al 2011, Papassotiropoulos et al 2002] may account for increased oxysterols found in CSF and compromised BBB functions may explain the accumulation of oxysterols at later stage. This data suggested along with A $\beta$ , total tau and phospho-tau, CSF 24OHC and 26OHC could be appropriate biomarkers for AD screening.

In contrast to the brain cholesterol metabolism, peripheral cholesterol metabolism is greatly influenced by diet, physical activity and medications. Therefore, 26OHC levels may be variable between and within individuals during sampling. As a result, circulating 26OHC levels affected by these confounders may complicate the use of it as a disease biomarker. Hence, interpretation of 26OHC levels in biomarker studies should be carefully considered. A recent randomized controlled trial suggests that reducing serum 26OHC levels by managing lifestyle and vascular factors over 2 years is beneficial for improving cognitive function related to memory [Sandebring-Matton et al 2021]. The study suggested the intervention is beneficial to reduce 27OHC particularly in individuals with the highest 27OHC levels and younger age. This suggest that managing oxysterol levels from young is beneficial to improve cognition, but it is possible that increased oxidative stress in ageing and neurodegeneration may overcome the benefits of managing vascular and lifestyle factors. Therefore, we also compared autooxidised circulating 7-oxysterol levels between healthy, MCI and AD. However, these were not significantly different in our meta-analysis. In a systematic analysis of oxysterols in the brains of patients with different stages of AD development, they identified increased levels of oxysterols including 7-oxysterols, 4 $\beta$ -hydroxycholesterol, 5 $\alpha$ ,6 $\alpha$ -epoxycholesterol, and 5 $\beta$ ,6 $\beta$ -epoxycholesterol [Testa et al 2016]. Toxicity of 7-oxysterols on neuronal cells are well documented in both *in vivo* and *in vitro* studies [Okabe et al 2014, Debbabi et al 2017, Yammine et al 2020]. In addition, 7-ketocholesterol levels has been reported to increase in AD CSF [Iriundo et al 2020]. However, it is not clear if circulating 7-oxysterols would transfer through BBB to add oxidative stress burden in the brain.

## Conclusions

In summary, this meta-analysis does not show significant changes to circulating oxysterols between healthy individuals and people with MCI and AD. One important factor comparing biomarker results across decades is the changes to the classification between MCI and AD. While early studies mainly based on clinical examinations, later studies included other biomarkers such as A $\beta$  or Tau to categorise disease groups. This will have significant impact on reported data on oxysterols. Another confounding factor for oxysterol data could be the

level of medication between healthy controls and AD patients. While most of the studies that enrol healthy controls does not undergo medications, AD patients could be on many different types of medications to control cognitive functions such as neuropsychiatric drugs, vitamins, anti-hypertensive agents or statins. These drugs may have confounding effects on oxysterol levels. In addition, diet and physical performance play important role in peripheral cholesterol levels that will affect cholesterol metabolites. In the context of this data and evidence from previous work suggest that the use of oxysterols as biomarkers in AD is a complex process and it may need careful analysis and modelling to find trends to predict AD risk.

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### Declaration of interest

Authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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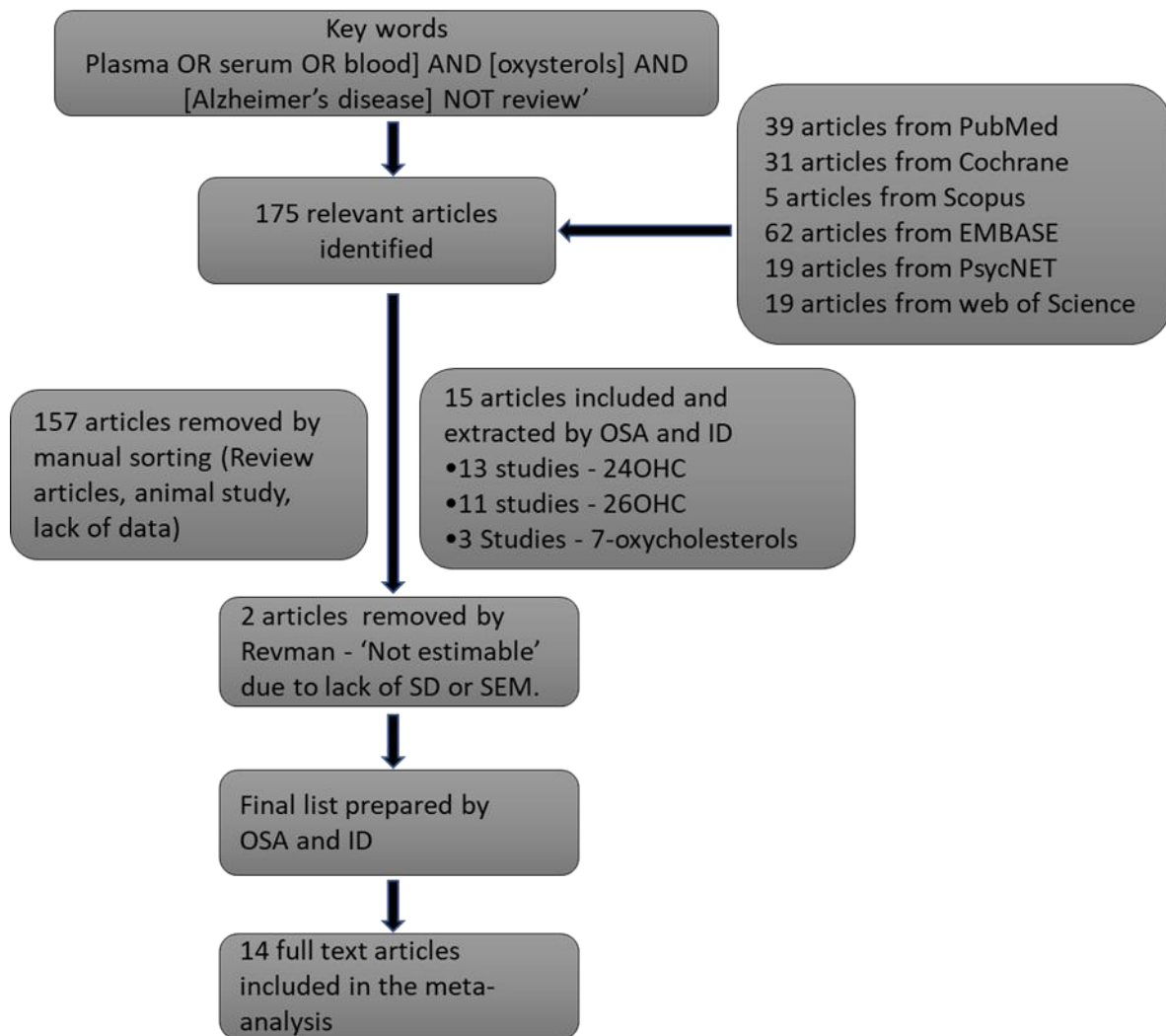
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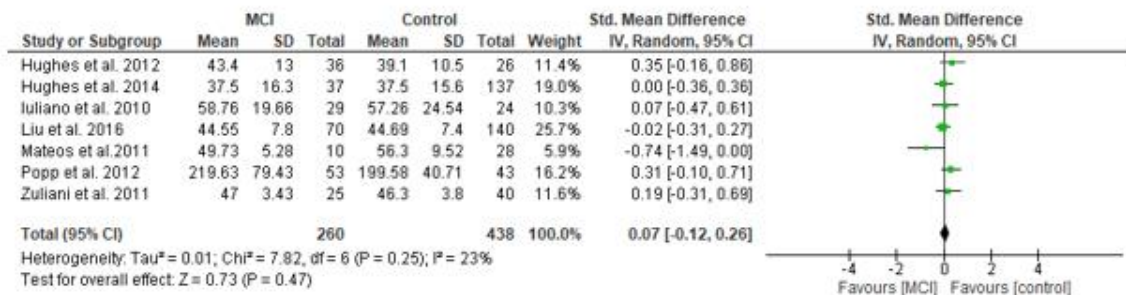
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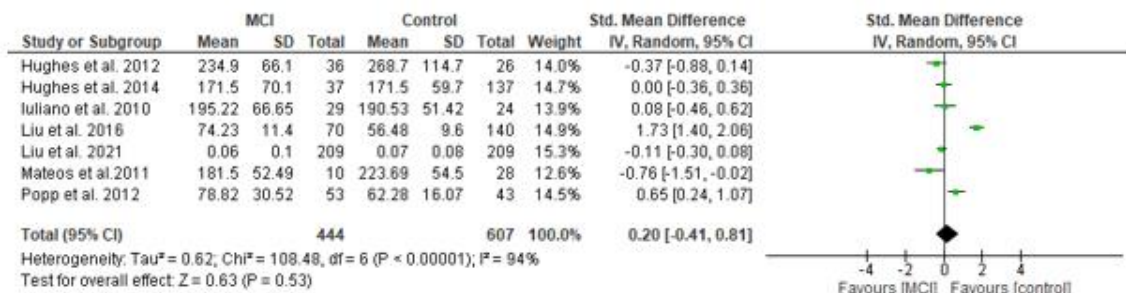
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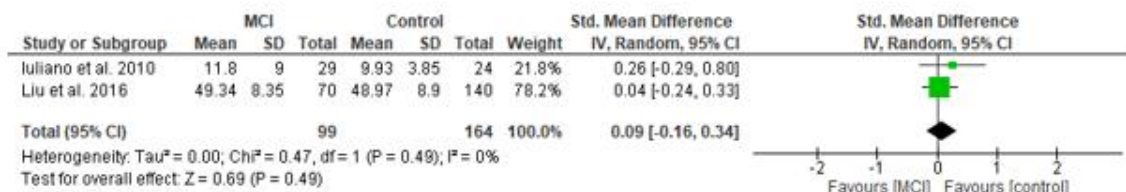
## 24OHC



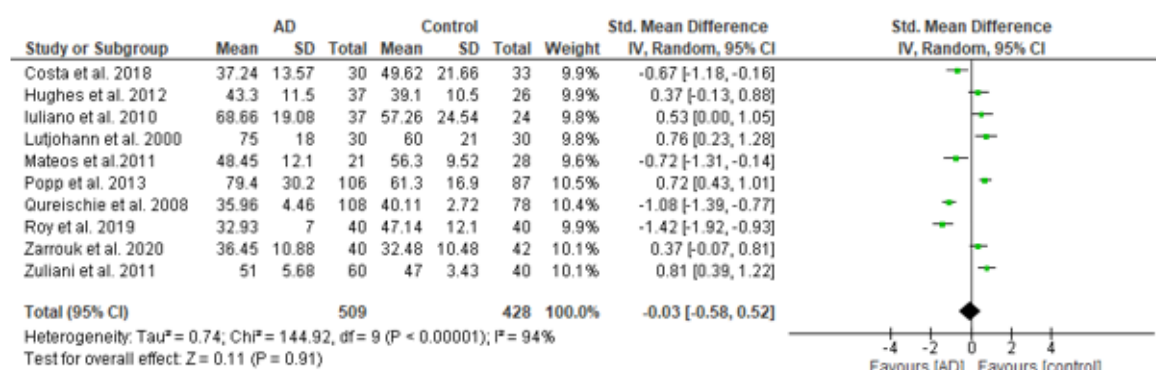
## 26OHC



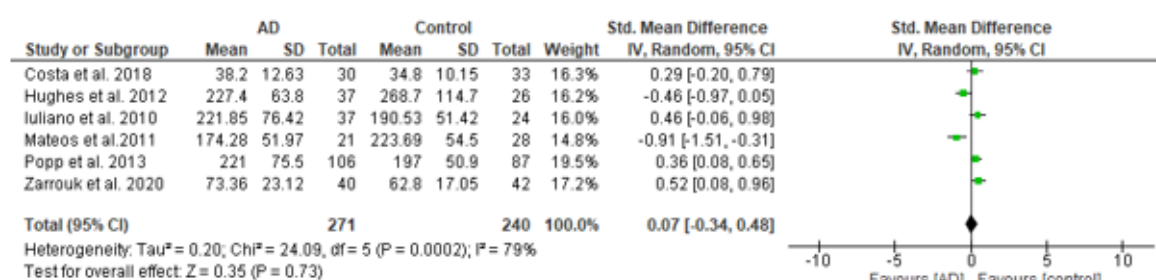
## 7-oxysterols



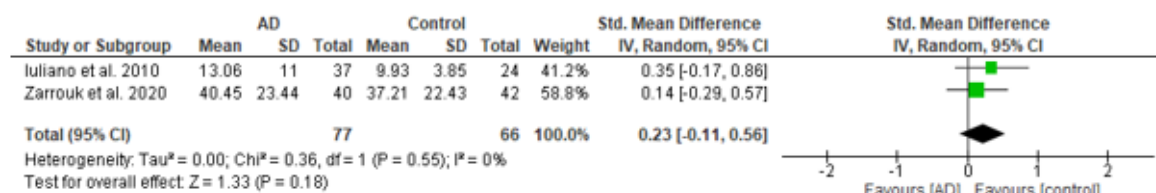
## 24OHC



## 26OHC



## 7-oxysterols



	Control	MCI	AD	Detection method	Reference
Costa et al. 2018 Sample numbers Age $\pm$ SD	33 73.88 $\pm$ 5.35		30 73.93 $\pm$ 6.46	GC-MS	[24]
Hughes et al. 2012 Sample numbers Age $\pm$ SD	26 80.2 $\pm$ 3.9	36	37 80.2 $\pm$ 3.8	GC-MS	[25]
Hughes et al. 2014 Sample numbers	137	37		GC-MS	[26]
Liu et al. 2016 Sample numbers Age, range	140 62-69	70 61-72		LC-MS	[23]
Liu et al. 2021 Sample numbers Age, range	209 60-67	209 59-66		LC-MS	[27]
Iuliano et al. 2010 Sample numbers Age $\pm$ SD	24 83 $\pm$ 6.4	29 70.86 $\pm$ 6.6	37 76.03 $\pm$ 7.9	GC-MS	[28]
lütjohann et al. 2000 Sample numbers Age (range)	30 49-91		30 52-87	GC-MS	[29]
Mateos et al. 2011 Sample numbers Age $\pm$ SD	28 57.81 $\pm$ 1.27	10 61.2 $\pm$ 2.33	21 67.3 $\pm$ 1.70	GC-MS	[30]
Popp et al. 2012 Sample numbers Age $\pm$ SD	43 67.33 $\pm$ 9.04		53 71.23 $\pm$ 8.29	GC-MS	[31]
Popp et al. 2013 Sample numbers Age $\pm$ SD	87 67.7 $\pm$ 9.13		106 71.1 $\pm$ 7.87	GC-MS	[32]
Qureischie et al. 2008 Sample numbers Age $\pm$ SD	78 72.4 $\pm$ 7.9		108 72.5 $\pm$ 8.8	GC-MS	[33]
Roy et al. 2019 Sample numbers Age $\pm$ SD	40 71.95 $\pm$ 6.27		40 70.20 $\pm$ 5.17	Sandwich ELISA	[34]
Zuliani et al. 2011 Sample numbers Age $\pm$ SD	40 73 $\pm$ 8.7	25 74 $\pm$ 8.2	60 78 $\pm$ 5.5	LC-MS	[35]
Zarrouk et al. 2020 Sample numbers Age, range	42 52-74		40 64-79	GC-MS	[36]