Estrogen receptor α gene polymorphisms and risk of Alzheimer’s disease: evidence from a meta-analysis

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Objectives: Human estrogen receptor α (ESR1), a member of the nuclear receptor superfamily of ligand-activated transcription factors, is one of the key mediators of hormonal response in estrogen-sensitive tissues. Accumulating evidence has demonstrated that two of the most widely studied single-nucleotide polymorphisms in ESR1 – PvuII (T/C, rs223493) and XbaI (A/G, rs9340799) – are possibly associated with Alzheimer’s disease (AD). However, individual study results are still controversial.

Materials and methods: We searched PubMed, Embase, Web of Science, Science Direct, SpringerLink, and the Chinese National Knowledge Infrastructure databases for eligible studies assessing the association of ESR1 polymorphisms and AD risk (last search performed in November 2013). Thereafter, a meta-analysis of 13,192 subjects from 18 individual studies was conducted to evaluate the association between ESR1 polymorphisms and susceptibility to AD.

Results: The results indicated that a significant association was found between the ESR1 PvuII polymorphism and AD risk in Caucasian populations (CC + CT versus TT, odds ratio [OR] 1.14, 95% confidence interval [CI] 1.02–1.28, P=0.03; CT versus TT, OR 1.16, 95% CI 1.02–1.31, P=0.02), whereas no evidence of association was found in Asian populations. Nevertheless, we did not find any significant association between the ESR1 XbaI polymorphism and AD risk for any model in Caucasian and Asian populations (all P>0.05).

Conclusion: Based on this meta-analysis, we conclude that the ESR1 PvuII polymorphism might be a risk factor in AD development in Caucasian populations, not in Asian populations. Further confirmation is needed from better-designed and larger studies.

Keywords: Alzheimer’s disease, estrogen receptor, polymorphism, meta-analysis

Introduction

Alzheimer’s disease (AD) is one of the main causes of dementia among elderly individuals, and is characterized by memory impairments and loss of cognitive functions, which eventually leads to complete incapacity and death of patients within 3–9 years after diagnosis.1 As the elderly population continues to grow, the prevalence of AD has increased remarkably worldwide. At present, AD is one of the leading causes of disability and death among the elderly.2–4 AD has emerged as a serious public health concern, affecting patients’ quality of life and placing an immense burden on the individual, family, and community. Therefore, elucidating the pathogenesis and risk factors of AD is of great significance for early detection, prevention, and control of the susceptible population.

Genetic, metabolic, and environmental factors play a role in the development and progression of AD.5 Recent genome-wide association studies have identified many genetic variances and single-nucleotide polymorphisms (SNPs) that are associated with...
AD risk. Estrogen-receptor gene polymorphisms are possible candidates for AD susceptibility. In women, estrogen loss associated with menopause status has been suggested to contribute to the development of AD. Estrogen has been shown to act as a neuroprotectant and a neurotrophic agent. Estrogen promotes neuronal cell survival, reduces neuronal injury, protects against neurotoxins, facilitates axonal sprouting and neuronal repair, and enhances synaptic transmission and neurogenesis. Recently, estrogen-replacement therapy has been proposed as a therapeutic approach to reduce the risk of developing AD and help patients with AD maintain their cognitive function. Estrogen exerts most of its effects through at least two major classes of receptors – estrogen receptor α (ESR1) and estrogen receptor β (ESR2). Human ESR1, a member of the nuclear receptor superfamily of ligand-activated transcription factors, is located on human chromosome 6q25, and is one of the key mediators of hormonal response in estrogen-sensitive tissues. After binding to estrogen, ESR1 acts as a transcriptional factor that regulates gene expression and function by interacting with regulatory regions of target genes. Many studies have demonstrated that ESR1 polymorphisms might influence ESR1 expression and affect estrogen function. To date, associations between ESR1 polymorphisms and cancer, coronary artery disease, hip fracture, and bone mineral density have been identified.

Accumulating evidence has demonstrated that two of the most widely studied SNPs in ESR1 – PvuII (T/C, rs223493) and XbaI (A/G, rs9340799) – are possibly associated with AD. However, the results of studies seeking associations of ESR1 with AD risk have not always been consistent in different population analyses. Therefore, we performed a meta-analysis of all eligible studies to provide a more comprehensive and reliable conclusion by evaluating the association between ESR1 gene polymorphisms and susceptibility to AD.

Materials and methods

Search strategy
We searched PubMed, Embase, Web of Science, Science Direct, SpringerLink, and the Chinese National Knowledge Infrastructure databases for eligible studies assessing the association of ESR1 polymorphisms and AD risk (last search updated to November, 2013). The search terms were “Alzheimer’s disease (AD) or dementia” in combination with “estrogen receptor or oestrogen receptor or estrogen” in combination with “polymorphism or variant or mutation”. There was no restriction on time period, sample size, population, language, or type of report in order to minimize potential publication bias.

Inclusion and exclusion criteria
Studies included in this meta-analysis had to meet the following criteria: 1) case-control studies or cohort studies, 2) studies investigating the association between ESR1 gene polymorphisms and AD risk, 3) sufficient data available to calculate an odds ratio (OR) with 95% confidence interval (CI), and 4) clinical diagnosis of AD based on standards of the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association. The exclusion criteria of the meta-analysis were: 1) case-control studies not focusing on the correlation between ESR1 polymorphisms and AD risk; 2) insufficient original data was available for data extraction; and 3) meta-analyses, letters, reviews, and editorial articles. If more than one study was published by the same author using the same patient population, the study with the largest size of samples was included.

Data extraction
Two authors (DC and BL) independently extracted the data from all eligible publications based on the inclusion criteria. The following information was recorded: name of first author, year of publication, country, ethnicity, number of cases and controls, the source of control, genotype method, distribution of genotypes, and Hardy–Weinberg equilibrium in controls. According to the source of control, eligible studies were defined as hospital-based and population-based. Ethnicity was simply categorized as Asian or Caucasian. Discrepancies were resolved by consensus and by consulting a third author.

Statistical analysis
Crude ORs with their corresponding 95% CIs were used to assess the strength of association between ESR1 polymorphisms and AD risk. The statistical significance of pooled ORs was assessed by the Z-test. Statistical heterogeneity across studies included in the meta-analysis was assessed by Cochran’s Q statistic and the I² test. P<0.10 and I²>50% were considered to be statistically significant heterogeneity, and the random-effects model or the fixed-effects model were used. Sensitivity analysis was performed using the leave-one-out method to test the reliability of the overall pooled results. Publication bias was evaluated by funnel plot and further assessed by Egger’s linear regression test and P<0.05 was considered representative of statistically
ESR1 and AD risk

significant publication bias. Data analyses were performed using Stata 11.0 (StataCorp, College Station, TX, USA) and RevMan 5.0 (Cochrane, Oxford, UK).

Results

Eligible studies

A flowchart of the process of study selection is shown in Figure 1. Based on the inclusion and exclusion criteria, a total of 17 articles were included in the meta-analysis after full-text review.9,24–39 The main characteristics of included studies are presented in Table 1. Of the 18 case-control studies included in the 17 articles, 18 studies investigated the ESR1 PvuII polymorphism (3,902 cases and 9,290 controls) and 17 studies investigated the ESR1 XbaI polymorphism (2,841 cases and 8,094 controls). Eight studies were performed in Caucasian populations,9,24,25,29–31,36,37 and ten studies were performed in Asian populations.26–28,32–35,37,39

The genotype distributions among the controls of all studies were in agreement with the Hardy–Weinberg equilibrium, except for one study for the ESR1 PvuII polymorphism25 and one study for the ESR1 XbaI polymorphism.44

Quantitative data synthesis

The results of this meta-analysis are presented in Table 2. The heterogeneity was significantly observed under all models (P<0.05) for the ESR1 PvuII and XbaI polymorphisms, which might have resulted from differences in ethnicity, country, source of controls, and genotype methods, so the random-effects model was used.

For the ESR1 PvuII polymorphism, a total of 18 studies including 3,902 cases and 9,290 controls were included in the meta-analysis. In the overall analysis, we did not find any significant association between the ESR1 PvuII polymorphism and AD risk in any comparison model (C allele versus T allele, OR 1.05, 95% CI 0.95–1.17, P=0.35; CC + CT versus TT, OR 1.13, 95% CI 0.98–1.32, P=0.10; CC versus CT + TT, OR 0.95, 95% CI 0.80–1.13, P=0.60; CC versus TT, OR 1.03, 95% CI 0.84–1.28, P=0.75; CT versus TT, OR 1.15, 95% CI 1.00–1.33, P=0.05). Subgroup analysis stratified by ethnicity showed a significant association between the ESR1 PvuII

Table 1 Characteristics of the 18 eligible studies included in the meta-analysis

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Country</th>
<th>Ethnicity</th>
<th>Source of controls</th>
<th>Sample size, (cases/controls)</th>
<th>SNP studied</th>
<th>Genotyping method</th>
<th>Genotype proportions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandi et al24</td>
<td>1999</td>
<td>Italy</td>
<td>Caucasian</td>
<td>PB</td>
<td>193/202</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.827, 0.364</td>
</tr>
<tr>
<td>Boada et al25</td>
<td>2012</td>
<td>Spain</td>
<td>Caucasian</td>
<td>PB</td>
<td>1,069/1,215</td>
<td>PvuII</td>
<td>Real-time PCR</td>
<td>0.024</td>
</tr>
<tr>
<td>Lambert et al9</td>
<td>2001</td>
<td>UK</td>
<td>Caucasian</td>
<td>PB</td>
<td>186/405</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.943, 0.159</td>
</tr>
<tr>
<td>Lin et al26</td>
<td>2003</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>PB</td>
<td>30/125</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.841, 0.051</td>
</tr>
<tr>
<td>Ji et al27</td>
<td>2000</td>
<td>Japan</td>
<td>Asian</td>
<td>PB</td>
<td>234/134</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.659, 0.679</td>
</tr>
<tr>
<td>Usui et al28</td>
<td>2006</td>
<td>Japan</td>
<td>Asian</td>
<td>PB</td>
<td>205/92</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.385, 0.150</td>
</tr>
<tr>
<td>Corbo et al29</td>
<td>2006</td>
<td>Italy</td>
<td>Caucasian</td>
<td>PB</td>
<td>277/212</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.193, 0.512</td>
</tr>
<tr>
<td>Monastero et al30</td>
<td>2006</td>
<td>Italy</td>
<td>Caucasian</td>
<td>PB</td>
<td>172/172</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.445, 0.062</td>
</tr>
<tr>
<td>Porrello et al31</td>
<td>2006</td>
<td>Italy</td>
<td>Caucasian</td>
<td>PB</td>
<td>131/109</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.103, 0.751</td>
</tr>
<tr>
<td>Li et al32</td>
<td>2004</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>PB</td>
<td>66/143</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.288, 0.867</td>
</tr>
<tr>
<td>Xu and Jia33</td>
<td>2002</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>PB</td>
<td>49/55</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.736, 0.869</td>
</tr>
<tr>
<td>Hou34</td>
<td>2009</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>PB</td>
<td>203/138</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.796, 0.036</td>
</tr>
<tr>
<td>Deng et al35</td>
<td>2013</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>HB</td>
<td>236/236</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.240, 0.475</td>
</tr>
<tr>
<td>den Heijer et al36</td>
<td>2004</td>
<td>Netherlands</td>
<td>Caucasian</td>
<td>PB</td>
<td>230/5,514</td>
<td>PvuII, XbaI</td>
<td>Taqman</td>
<td>0.802, 0.627</td>
</tr>
<tr>
<td>Maryama et al37</td>
<td>2000</td>
<td>Japan</td>
<td>Asian</td>
<td>PB</td>
<td>183/133</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.068, 0.061</td>
</tr>
<tr>
<td>Maryama et al37</td>
<td>2000</td>
<td>UK</td>
<td>Caucasian</td>
<td>PB</td>
<td>156/120</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.903, 0.661</td>
</tr>
<tr>
<td>Ma et al38</td>
<td>2009</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>PB</td>
<td>219/215</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.424, 0.962</td>
</tr>
<tr>
<td>Zhou et al39</td>
<td>2008</td>
<td>People’s Republic of China</td>
<td>Asian</td>
<td>PB</td>
<td>63/70</td>
<td>PvuII, XbaI</td>
<td>PCR-RFLP</td>
<td>0.858, 0.142</td>
</tr>
</tbody>
</table>

Abbreviations: PB, population-based; HB, hospital-based; HWE, Hardy–Weinberg equilibrium; PCR, polymerase chain reaction; RFLP, restriction fragment length polymorphism; SNP, single-nucleotide polymorphism.
Table 2  Association between ESR1 polymorphisms and Alzheimer's disease risk

<table>
<thead>
<tr>
<th>Allele model</th>
<th>Dominant model</th>
<th>Recessive model</th>
<th>Homozygous comparison</th>
<th>Heterozygous comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>P</td>
<td>OR (95% CI)</td>
<td>P</td>
</tr>
<tr>
<td>PvuII T/C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>1.05 (0.95–1.17)</td>
<td>0.35</td>
<td>0.95 (0.80–1.13)</td>
<td>0.60</td>
</tr>
<tr>
<td>Caucasian</td>
<td>1.06 (0.98–1.15)</td>
<td>0.12</td>
<td>1.01 (0.88–1.15)</td>
<td>0.89</td>
</tr>
<tr>
<td>Asian</td>
<td>1.06 (0.87–1.30)</td>
<td>0.55</td>
<td>0.91 (0.61–1.37)</td>
<td>0.31</td>
</tr>
<tr>
<td>XbaI A/G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>1.05 (0.90–1.23)</td>
<td>0.53</td>
<td>1.00 (0.75–1.34)</td>
<td>0.99</td>
</tr>
<tr>
<td>Caucasian</td>
<td>1.02 (0.85–1.22)</td>
<td>0.84</td>
<td>1.00 (0.70–1.42)</td>
<td>0.99</td>
</tr>
<tr>
<td>Asian</td>
<td>1.10 (0.84–1.43)</td>
<td>0.50</td>
<td>1.03 (0.62–1.70)</td>
<td>0.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Odds ratio</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>1.23 (0.91–1.67)</td>
<td>0.12</td>
</tr>
<tr>
<td>Caucasian</td>
<td>1.14 (1.02–1.28)</td>
<td>0.03</td>
</tr>
<tr>
<td>Asian</td>
<td>1.16 (1.02–1.31)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Abbreviations: ESR1, estrogen receptor α; OR, odds ratio; CI, confidence interval.

Polymorphism and AD risk under the dominant model (CC + CT versus TT, OR 1.14, 95% CI 1.02–1.28, P=0.03; Figure 2) and heterozygous comparison (CT versus TT, OR 1.16, 95% CI 1.02–1.31, P=0.02), whereas no evidence of association was found under the allele model (C allele versus T allele, OR 1.06, 95% CI 0.98–1.15, P=0.12), recessive model (CC versus CT + TT, OR 1.01, 95% CI 0.88–1.15, P=0.89), or homozygous comparison (CC versus TT, OR 1.10, 95% CI 0.98–1.28).
0.94–1.28, P=0.23) in Caucasian populations. Nevertheless, we did not find any significant association between the ESR1 PvuII polymorphism and AD risk under any model in the Asian population (all P>0.05).

For the ESR1 XbaI polymorphism, a total of 17 studies including 2,841 cases and 8,094 controls were included in the meta-analysis. Overall, there was no evidence of an association between the ESR1 XbaI polymorphism and AD risk in different genetic models when all the eligible studies were pooled into the meta-analysis (G allele versus A allele, OR 1.05, 95% CI 0.90–1.23, P=0.53; GG + GA versus AA, OR 1.07, 95% CI 0.89–1.30, P=0.47 [Figure 3]; GG versus GA + AA, OR 1.00, 95% CI 0.75–1.34, P=0.99; GG versus AA, OR 1.04, 95% CI 0.74–1.45, P=0.84; GA versus AA, OR 1.04, 95% CI 0.93–1.16, P=0.50). The association of the ESR1 XbaI polymorphism with AD was further stratified by ethnicity. Neither Caucasian populations nor Asian populations showed a significant association between the ESR1 XbaI polymorphism and AD risk in any model (all P>0.05) (Figure 3).

### Sensitivity analysis
A sensitivity analysis was performed to assess the influence of each individual study on the pooled ORs through omitting study or subgroup.

#### 4.1.1 Caucasian subgroup
Brandi et al\(^\text{34}\) 6.6% 1.31 (0.87–1.97)
Corbo et al\(^\text{39}\) 6.8% 1.30 (0.89–1.91)
den Heijer et al\(^\text{36}\) 7.9% 1.00 (0.77–1.31)
Lambert et al\(^\text{9}\) 7.1% 0.97 (0.68–1.38)
Maruyama et al\(^{37,3}\) 5.8% 1.33 (0.81–2.19)
Monastero et al\(^\text{30}\) 6.0% 0.52 (0.32–0.82)
Porrello et al\(^\text{31}\) 5.6% 1.05 (0.63–1.75)

Subtotal (95% CI) 45.8% 1.03 (0.83–1.28)

Total events
Heterogeneity: χ\(^2\)=12.42; df=6 (P=0.05); I\(^2\)=52%
Test for overall effect: Z=0.28 (P=0.78)

#### 4.1.2 Asian subgroup
Deng et al\(^\text{35}\) 7.0% 0.65 (0.45–0.94)
Hou\(^\text{34}\) 6.3% 1.40 (0.91–2.16)
Ji et al\(^\text{27}\) 6.3% 1.73 (1.12–2.68)
Lin et al\(^\text{36}\) 3.5% 2.28 (1.00–5.17)
Li et al\(^\text{32}\) 4.9% 1.34 (0.73–2.44)
Ma et al\(^\text{39}\) 7.0% 0.80 (0.55–1.15)
Maruyama et al\(^{37,3}\) 5.8% 0.92 (0.57–1.51)
Usui et al\(^\text{28}\) 5.7% 0.85 (0.52–1.41)
Xu and Jia\(^\text{33}\) 3.5% 4.24 (1.87–9.63)
Zhou et al\(^\text{40}\) 4.2% 0.48 (0.24–0.96)

Subtotal (95% CI) 54.2% 1.14 (0.82–1.57)

Total events
Heterogeneity: χ\(^2\)=36.32; df=9 (P=0.0001); I\(^2\)=75%
Test for overall effect: Z=0.77 (P=0.44)

Total (95% CI) 100.0% 1.07 (0.89–1.30)

Total events
Heterogeneity: χ\(^2\)=48.73; df=16 (P=0.0001); I\(^2\)=67%
Test for overall effect: Z=0.73 (P=0.47)
Test for subgroup differences: χ\(^2\)=0.24; df=1 (P=0.63); I\(^2\)=0%

**Figure 3** Forest plots of ESR1 XbaI polymorphism and Alzheimer’s disease risk in Caucasian and Asian populations (dominant model, GG + GA versus AA).

**Notes:** Random model of meta-analysis was employed for calculation of the combined ORs and P-values. Caucasian population, OR 1.03, CI 0.83–1.28, P=0.78; Asian population, OR 1.14, CI 0.82–1.57, P=0.44. The study of Maruyama et al\(^\text{37}\) was performed in Asian populations (a), and Caucasian populations (b).

**Abbreviations:** M-H, Mantel-Haenszel; CI, confidence interval; OR, odds ratio; ESR1, estrogen receptor α.
individual studies. Statistically similar results were obtained after sequentially excluding each study, suggesting the stability of this meta-analysis.

Publication bias

The shapes of the funnel plots did not reveal any evidence of obvious asymmetry visually under the dominant model of PvuII and XbaI polymorphisms (Figure 4). Also, there was no statistical evidence of publication bias among studies using Egger’s regression test for the PvuII (P=0.296) and XbaI (P=0.206) polymorphisms.

Discussion

The ESR1 gene is critical for hormone binding, deoxyribonucleic acid binding, and activation of transcription, because it encodes an estrogen receptor that is key in the mediation of hormonal response in estrogen-sensitive tissues. Given that the effect of a hormone is given by the interaction with its receptor, genetic changes in the ESR1 gene may lead to differences in ESR1 expression and estrogen metabolism, and thereby possibly explain interindividual differences in cognitive impairment or AD risk. Several SNPs have been identified in ESR1, and among these identified SNPs, PvuII (T/C, rs2234693) and XbaI (A/G, rs9340799), which are located in intron 1 of the ESR1 gene, 397 and 351 base pairs upstream of exon 2, respectively, are the most studied. Many previous genetic studies have investigated the function of ESR1 PvuII and XbaI polymorphisms in the etiology of AD, but the results remain inconclusive. Bertram et al reported that ESR1 PvuII and XbaI polymorphisms were associated with AD risk, and the ESR1 gene could be a candidate gene in the development of AD using a systematic meta-analysis. Another meta-analysis by Luckhaus and Sand indicated that ESR1 PvuII and XbaI polymorphisms were confirmed to modulate susceptibility to AD in Asian individuals, but not in Europeans. However, only eleven studies and eight studies were included in Bertram et al’s and Luckhaus and Sand’s studies, respectively. Therefore, we performed a meta-analysis to update previous meta-analyses, and provide a more comprehensive and reliable analysis of the association between ESR1 PvuII and XbaI polymorphisms and AD risk.

This meta-analysis included 18 case-control studies with 3,902 cases and 9,290 controls for the PvuII polymorphism, and 17 case-control studies with 2,841 cases and 8,094 controls for the XbaI polymorphism. In the overall analysis, the ESR1 PvuII polymorphism was not associated with AD risk. In the analysis stratified by ethnicity, the ESR1 PvuII polymorphism was associated with AD susceptibility in Caucasian populations, while there was no evidence of an association between the ESR1 PvuII polymorphism and AD risk in Asian populations, which suggested that the differences in genetic background may affect AD susceptibility due to different ethnicities with different allele frequencies. Although the exact mechanism of the PvuII polymorphism in the development of AD is not yet clear, a possible reason could be that the PvuII polymorphism produces a binding site for a specific transcription factor that may affect gene expression, while the presence of the C allele in the PvuII site was associated with decreased ESR1 transcription and, consequently, a low number of receptors. However, neither Caucasian populations nor Asian populations showed statistically significant associations between the ESR1 XbaI polymorphism and AD risk. Given that the PvuII and XbaI polymorphisms are in strong linkage disequilibrium, it is difficult to determine which of the two polymorphic sites is driving the association.
In our meta-analysis, the results suggested that the *ESR1* PvuII polymorphism may be of importance in AD risk in Caucasian populations. These findings are not consistent with previous meta-analyses, our results indicated that only the *ESR1* PvuII polymorphism may alter the risk of AD in Caucasian populations, not in Asian populations, suggesting multiple and different genes are involved in the pathophysiological process of AD in different ethnicities.

Several limitations should not be ignored when interpreting the results. First, all eligible studies were from Caucasian and Asian populations; therefore, our results were limited to these two populations. More studies containing the full range of possible ethnic differences are needed to avoid selection bias. Second, AD is a multifactorial disease involving complex gene–gene or gene–environment interactions. In this study, we had insufficient data to evaluate such interactions for the independent role of *ESR1* polymorphisms in AD risk. Third, we did not perform subgroup analysis by sex, age, or different stage of AD, due to limited data in primary studies. Fourth, because only published studies were included in this study, publication bias may have occurred, even though no statistical test bias was found.

**Conclusion**

In summary, this meta-analysis indicates that the *ESR1* PvuII polymorphism is associated with increased AD risk in Caucasian populations, but not in Asian populations. However, no significant association was observed for the *ESR1* XbaI polymorphism and AD risk. This result should be interpreted cautiously. To confirm or refute this result, well-designed studies with larger sample sizes and more ethnic groups are required to elucidate this association further.

**Acknowledgment**

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**Disclosure**

The authors report no conflicts of interest in this work.

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