A Genome-Wide Association Study Identified AFF1 as a Susceptibility Locus for Systemic Lupus Erythematosus in Japanese

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Abstract

Systemic lupus erythematosus (SLE) is an autoimmune disease that causes multiple organ damage. Although recent genome-wide association studies (GWAS) have contributed to discovery of SLE susceptibility genes, few studies has been performed in Asian populations. Here, we report a GWAS for SLE examining 891 SLE cases and 3,384 controls and multi-stage replication studies examining 1,387 SLE cases and 28,564 controls in Japanese subjects. Considering that expression quantitative trait loci (eQTLs) have been implicated in genetic risks for autoimmune diseases, we integrated an eQTL study into the results of the GWAS. We observed enrichments of cis-eQTL positive loci among the known SLE susceptibility loci (30.8%) compared to the genome-wide SNPs (6.9%). In addition, we identified a novel association of a variant in the AF4/FMR2 family, member 1 (AFF1) gene at 4q21 with SLE susceptibility (rs340630; P = 8.3 x 10^-3, odds ratio = 1.21). The risk A allele of rs340630 demonstrated a cis-eQTL effect on the AFF1 transcript with enhanced expression levels (P = 0.05). As AFF1 transcripts were prominently expressed in CD4+ and CD19+ peripheral blood lymphocytes, up-regulation of AFF1 may cause the abnormality in these lymphocytes, leading to disease onset.


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**Introduction**

Systemic lupus erythematosus (SLE) is an autoimmune disease characterized by autoantibody production, complement activation, and multi-organ damage [1]. Familial aggregation demonstrates that both genetic and environmental factors play a role in pathogenesis of SLE [2]. Genetic studies using candidate gene approaches, and recently, genome-wide association studies (GWAS), have uncovered more than 25 SLE susceptibility genes, including *HLA-DRB1*, *IRF5*, *STAT4*, *ITGAM*, *BLK*, *TNEAP3*, and others [3–18]. However, most of these studies were conducted in European populations [3–13,15,17], and few studies have been conducted in Asian populations [14,16,18]. Since the epidemiology of SLE has demonstrated that the prevalence of disease substantially differs among populations, genetic backgrounds of SLE should be also heterogeneous across populations [19,20]. Therefore, additional studies in Asians might provide novel insights. It is of note that GWAS for SLE in Chinese populations identified novel loci that had not been detected in Europeans, such as *ETSI*, *IKZF1*, and *WDFY4* [14,16].

Another issue raised by the previous GWASs for complex diseases is that many susceptibility loci still remained uncaptured, owing to its strict significance threshold for multiple hypothesis testing [21]. In SLE, for example, the 26 risk loci identified by the previous GWAS explained only an estimated 8% of the total genetic susceptibility to the disease [15]. Therefore, it is still important to examine the sub-loci of GWAS, in order to reveal the entire picture of genetic etiology. To effectively explore these uncaptured loci, prioritization of GWAS results by incorporating additional information implicated in the disease pathophysiology is recommended [22,23]. Considering that abnormalities in B cell activity play essential roles in SLE, prioritization based on an expression quantitative trait loci (eQTLs) study for B cells would be a promising approach. In this study, we report a GWAS and multi-stage replication studies for SLE examining 2,278 SLE cases and 31,948 controls in Japanese subjects. We integrated eQTL study into the results of the GWAS and identified *AFF1* as a novel SLE susceptibility loci. We also confirmed cis-regulatory effect of the locus on the *AFF1* transcript. Our study would be one of the initial successes for detecting novel genetic locus using the eQTL study, and it should contribute to our understanding of the genetic loci being uncaptured by standard GWAS approaches.

**Results**

**GWAS for SLE**

In the GWAS, 891 SLE cases and 3,384 controls in Japanese subjects were genotyped over 550,000 single nucleotide polymorphism (SNP) markers (Table S1, S2 and Figure 1). We applied stringent quality control (QC) criteria and evaluated associations of 430,797 autosomal SNPs, as previously described [26]. No substantial population stratification was demonstrated through principal component analysis (Figure S1) or a Quantile–Quantile plot of *P*-values (inflation factor, λ*GC* = 1.088, Figure S2), suggesting homogenous ancestries of our study population [27].

We identified significant associations in six chromosomal loci that satisfied the genome-wide significance threshold of *P* < 5.0 × 10^-8 (Table 1 and Figure 2A). These loci have been reported to be associated with SLE susceptibility (*STAT4*, *TNEAP3*, *HIP1*, *BLK*, *ETSI*, and the HLA region) [3–18]. We also observed significant replications in 17 of the previously reported susceptibility loci [3–18] (x = 0.01; Table 2). Of these, significant replications were enriched in the loci identified through the studies in Asian populations (80%; 8 of the 10 loci), including *RASGRP3*, *IKZF1*, *HIP1*, *WDFY4*, intergenic region at 11q23, *ETSI*, *SLC15A4*, *ELF1*, and *HIC2-UBE2L3* [14,16,18], compared to those in European populations (56.3%; 9 of the 16 loci) [3–13,15,17].

**Incorporation of eQTL study into GWAS results**

For the selection of SNPs incorporated in the replication studies of the potential association signals, we evaluated cis-eQTL effects of the SNPs using publically available gene expression data [28], and prioritized the results of the GWAS. After applying QC criteria, we evaluated the expression levels of 19,047 probes assayed in lymphoblastoid B cell lines from Phase II HapMap East-Asian individuals [29] using Illumina’s human whole-genome expression array (WG-6 version 1) [28]. For each of the SNPs included in our GWAS, probes located within ±300 kbp regions were focused on as cis-eQTLs (average 4.93 probes per SNP). We denoted the SNPs which exhibited significant associations with expression levels of any of the corresponding cis-eQTLs as eQTL positive (false discovery rate (FDR) *P*-values < 0.05). We observed enrichments of eQTL positive loci among the SLE susceptibility loci (30.8%; 8 of the 26 evaluated loci) including a well-known eQTL gene of *BLK* [11,25] (Table 2), compared to the genome-wide SNPs (6.9%) and compared even to the SNPs in the vicinity of expressed loci (among the SNPs located within ±10 kbp of probes used for the expression analysis, 13.1% were eQTL positive; Table S3).

By prioritizing the results of the GWAS using the eQTL study, we selected 57 SNPs from 1,207 SNPs that satisfied *P* < 1.0 × 10^-3 in the GWAS. We subsequently referred the associations of the selected SNPs using the results of the concurrent genome-wide scan for SLE in an independent Japanese population (Tahira T et al. Presented at the 59th Annual Meeting of the American Society of Human Genetics, October 21, 2009). In the scan, 447 SLE cases and 680 controls of Japanese origin were evaluated using a pooled DNA approach [30]. We selected SNPs if any association signals were observed in the neighboring SNPs of the...
pooled analysis. As a result, 8 SNPs remained for further investigation (Table S4).

Replication studies and identification of **AFF1**

Then, we performed two-stage replication studies using independent SLE cohorts for Japanese subjects (cohort 1 with 562 SLE cases and 653 controls, and cohort 2 with 825 SLE cases and 27,911 controls). First, we evaluated the selected 8 SNPs in the replication study 1. In the replication study 2, 2 SNPs that satisfied $P<1.0 \times 10^{-6}$ in the combined study of GWAS and replication study 1 were further evaluated (Figure 1). Among the evaluated SNPs, we observed significant replications in the SNP located in the genomic region of the AFF/FMR2 family, member 1 gene (AFF1) at 4q21 (rs340630; $P=4.6 \times 10^{-5}$ and $P=0.0094$ in the two individual cohorts, respectively; Table 3, Table S5, and Figure 2B). The combined study for the GWAS ($P=1.5 \times 10^{-7}$) and the replication studies demonstrated significant associations of rs340630 that satisfied the genome-wide significance threshold ($P=8.3 \times 10^{-9}$, OR = 1.21, 95% CI 1.14–2.30).

Cis-eQTL effect of rs340630 on **AFF1** transcripts

Since the landmark SNP in the **AFF1** locus, rs340630, was prioritized through the eQTL study as an eQTL positive SNP (Table 3), we further validated its cis-eQTL effect using Epstein-Barr virus (EBV)-transfected B cell lines established from Japanese individuals [Pharma SNP Consortium (PSC) cells, n = 62]. The correlation between rs340630 genotypes and the expression levels of **AFF1** was significant in the PSC cells stimulated with phorbol myristate acetate (PMA) ($R^2 = 0.074$, $P=0.033$; Figure 3A). The expression levels increased with the number of SLE-risk (A) alleles. To further confirm this cis-regulatory effect, we performed allele-specific transcript quantification (ASTQ) of **AFF1**. The transcript levels of each allele were quantified by qPCR using an allele specific probe for a SNP in the 5’-untranslated region (rs340638), which was in absolute LD with rs340630 ($r^2 = 1.0$, $D’ = 1.0$). We examined PSC-cells (n = 17) that were heterozygous for both rs340630 and rs340638. The mean ratio of each transcript (A over G allele; the A allele comprises a haplotype with the risk (A) allele of rs340630) were significantly increased to 1.07 compared to the ratio of the amount of DNA (1.00, $P=0.012$) (Figure 3B). These results suggest that rs340630, or SNP(s) in LD with it, are a regulatory variant predisposing SLE susceptibility through increased expression levels of **AFF1**.

Expression of **AFF1** in CD4+ and CD19+ peripheral blood lymphocytes

**AFF1** is known to be involved in cytogenetic translocations of acute lymphoblastic leukemia (ALL) [31]. Its fusion protein with the mixed-lineage leukemia gene (MLL) is implicated in the regulation of transcription and the cell cycle of lymphocytes [31]. To investigate the expression pattern of **AFF1** in normal tissues, we evaluated the transcript levels of **AFF1** in a panel of various tissues. We observed prominent expression of **AFF1** in CD4+ and CD19+ peripheral blood lymphocytes, implying an important role for **AFF1** in helper-T-cells and B-cells (Figure 3C).

Discussion

Through a GWAS and multi-staged replication studies consisting of 2,278 SLE cases and 31,948 controls in Japanese subjects, our study identified that the **AFF1** locus was significantly associated with SLE susceptibility.

As well as the identification of the novel SLE susceptibility locus, we observed significant replications of associations in the previously reported susceptibility loci. The replications were especially enriched in the loci identified through the studies in Asian populations, compared to those in European populations. Considering the ethnic heterogeneities in the epidemiology of SLE [19,20], these observations suggest the similarities in the genetic backgrounds of SLE shared within Asian populations, and also the existence of the both common and divergent genetic backgrounds encompassed between European and Asian populations.
Association of AFF1 with SLE

Table 1. Results of a genome-wide association study for Japanese patients with SLE.

<table>
<thead>
<tr>
<th>rsID*</th>
<th>Chr</th>
<th>Position (bp)</th>
<th>Cytoband</th>
<th>Gene</th>
<th>Alleleb</th>
<th>No. subjects</th>
<th>Allele 1 freq.</th>
<th>OR (95%CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/2</td>
<td>Case Control</td>
<td>Case Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rs10168266</td>
<td>2</td>
<td>191,644,049</td>
<td>2q32</td>
<td>STAT4</td>
<td>T/C</td>
<td>891</td>
<td>3,384</td>
<td>0.37</td>
<td>0.27</td>
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<td>rs9501626</td>
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<td>32,508,322</td>
<td>6p21</td>
<td>HLA region</td>
<td>A/C</td>
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<td>3,381</td>
<td>0.20</td>
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<td>6q23</td>
<td>TNFAIP3</td>
<td>G/T</td>
<td>891</td>
<td>3,377</td>
<td>0.11</td>
<td>0.069</td>
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<td>7q11</td>
<td>HIP1</td>
<td>G/A</td>
<td>891</td>
<td>3,384</td>
<td>0.25</td>
<td>0.19</td>
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<tr>
<td>rs2254546</td>
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<td>11,381,089</td>
<td>8p23</td>
<td>BLK</td>
<td>G/A</td>
<td>891</td>
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<td>127,816,269</td>
<td>11q24</td>
<td>ETS1</td>
<td>A/G</td>
<td>891</td>
<td>3,368</td>
<td>0.48</td>
<td>0.39</td>
</tr>
</tbody>
</table>

To effectively detect the novel SLE susceptibility locus, we integrated cis-eQTL effects of the SNPs and prioritized the results of the GWAS. In addition to identifying a novel locus for SLE-susceptibility, our study demonstrated approximately 30% of confirmed SLE-susceptibility loci were comprised of cis-eQTLs. We also confirmed cis-regulatory effect of the landmark SNP in the AFF1 locus, rs340630, on AFF1 transcripts, which had been prioritized through the eQTL study. These results would suggest that accumulation of quantitative changes in gene expression would accelerate the disease onset of SLE. It would also demonstrate the validity of applying eQTL study in the search of the susceptible genes for SLE or other autoimmune diseases, as previously suggested in the study for celiac disease [24]. To our knowledge, this is one of the initial studies to successfully discover a new locus by prioritizing GWAS results using eQTLs, and should contribute to the approaches assessing genetic loci still being uncaptured by recent large-scaled GWASs due to stringent significance threshold for multiple hypothesis testing [21].

We observed prominent expression levels of AFF1 in CD4+ and CD19+ peripheral blood lymphocytes, which would imply an important role for AFF1 in helper-T-cells and B-cells. In fact, AFF1 is essential for normal lymphocyte development, as demonstrated in mice deficient for AFF1 as a novel susceptibility locus for SLE. Moreover, the association signals based on individual genotyping were 2.7 × 10^{−16} and 1.0 × 10^{−18}, respectively, which are significant associations that could have induced potential bias on the results of the association analysis of the SNPs. However, considering the homogeneous ancestries of the Japanese population [27] and that principal component analysis did not demonstrate significant population stratification in the control cases, the control-case ratio of the subjects were relatively high in the replication study 2 ( = 33.8), and this disproportionate ratio could have induced potential bias on the results of the association analysis of the SNPs. However, considering the homogeneous ancestries of the Japanese population [27] and that principal component analysis did not demonstrate significant population stratification in the control cases, the bias owing to population stratification might not be substantial.

In summary, through a GWAS and multi-staged replication studies in a Japanese population integrating eQTL study, our study identified AFF1 as a novel susceptibility locus for SLE.

Materials and Methods

Subjects
We enrolled 2,278 systemic lupus erythematosus (SLE) cases and 31,948 controls. SLE cases enrolled in the genome-wide association study (GWAS) (n = 891) or part of the 2nd replication study (n = 83) were collected from 12 medical institutes in Japan under the support of the autoimmune disease study group of Research in Intractable Diseases, Japanese Ministry of Health, Labor and Welfare: Hokkaido University Graduate School of Medicine, Tohoku University Graduate School of Medicine, the University of Tokyo, Keio University School of Medicine, Juntendo University School of Medicine, University of Occupational and Environmental Health, University of Tsukuba, Tokyo Medical and Dental University, National Center for Global Health and Medicine, Nagasaki University, Wakayama Medical University, and Jichi Medical University. SLE cases (n = 562) and controls (n = 653) enrolled in the 1st replication study were collected from Kyushu University. Some of the SLE cases (n = 742) and controls (n = 27,911) enrolled in the 2nd replication study were collected from Kyoto University, Tokyo Women’s
Medical University, the University of Tokyo, and the BioBank Japan Project [36]. All subjects were of Japanese origin and provided written informed consent. SLE cases met the revised American College of Rheumatology (ACR) criteria for SLE [37]. Control subjects were confirmed to be free of autoimmune disease. Some of the SLE cases were included in our previous studies [38–40]. Details of the subjects are summarized in Table S1 and S2. This research project was approved by the ethical committees of the University of Tokyo, RIKEN, and affiliated medical institutes.
Table 2. Associations among previously reported SLE-related loci.

<table>
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<tr>
<th>rsID</th>
<th>Chr</th>
<th>Position (bp)</th>
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<th>Gene</th>
<th>Allele</th>
<th>Allele 1 freq.</th>
<th>OR (95%CI)</th>
<th>P</th>
<th>eQTL (b)</th>
<th>Identified by the studies in (a)</th>
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<td>Control</td>
<td>Case</td>
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<td>1q25</td>
<td>TNFSF4</td>
<td>T/G</td>
<td>0.23</td>
<td>1.19–1.54</td>
<td>3.0 × 10^-6</td>
<td>+</td>
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<td>rs3024505</td>
<td>1</td>
<td>205,006,527</td>
<td>1q32</td>
<td>IL10</td>
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<td>0.90–2.00</td>
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<td>2q32</td>
<td>STAT4</td>
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<td>BANK1</td>
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<td>1.07–1.53</td>
<td>0.0070</td>
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<td>PDHKL1</td>
<td>T/C</td>
<td>0.75</td>
<td>1.00–1.27</td>
<td>0.056</td>
<td>+</td>
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<tr>
<td>rs4639966</td>
<td>11</td>
<td>75,018,280</td>
<td>11q23</td>
<td>Intergenic</td>
<td>T/C</td>
<td>0.32</td>
<td>1.09–1.36</td>
<td>7.3 × 10^-4</td>
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<tr>
<td>rs6593300</td>
<td>11</td>
<td>127,816,269</td>
<td>11q24</td>
<td>ETS1</td>
<td>A/G</td>
<td>0.48</td>
<td>1.30–1.60</td>
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<td>128,667,467</td>
<td>12q24</td>
<td>SLC15A4</td>
<td>T/C</td>
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<td>1.06–1.38</td>
<td>0.0057</td>
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<tr>
<td>rs7329174</td>
<td>13</td>
<td>40,456,110</td>
<td>13q14</td>
<td>ELF1</td>
<td>G/A</td>
<td>0.30</td>
<td>1.18–1.49</td>
<td>2.2 × 10^-5</td>
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</tr>
<tr>
<td>rs7197475</td>
<td>16</td>
<td>30,550,368</td>
<td>16p11</td>
<td>Intergenic</td>
<td>T/C</td>
<td>0.12</td>
<td>1.02–0.41</td>
<td>0.031</td>
<td>+</td>
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<tr>
<td>rs11150610</td>
<td>16</td>
<td>31,241,737</td>
<td>16p11</td>
<td>ITGAM</td>
<td>C/A</td>
<td>0.20</td>
<td>0.94–2.22</td>
<td>0.32</td>
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<tr>
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<td>13,674,531</td>
<td>17p12</td>
<td>Intergenic</td>
<td>T/C</td>
<td>0.28</td>
<td>0.91–1.15</td>
<td>0.73</td>
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<td>20,139,185</td>
<td>22q11</td>
<td>HIC2UB2L3</td>
<td>T/C</td>
<td>0.52</td>
<td>1.08–1.33</td>
<td>6.1 × 10^-4</td>
<td>+</td>
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</tr>
</tbody>
</table>

*Defined using gene expression data measured in lymphoblastoid B cell lines [28].

(a)Defined using gene expression data measured in lymphoblastoid B cell lines [28].

(b)Based on forward strand of NCBI Build 36.3.

(c)Based on the previously reported studies for SLE susceptibility loci [3–18].

Genotyping and quality control
In GWAS, 946 SLE cases and 3,477 controls were genotyped using Illumina HumanHap550v3 BeadChips (Illumina, CA, USA), respectively. After the exclusion of 47 SLE cases and 92 controls with call rates <0.98, SNPs with call rates <0.99 in SLE cases or controls,

Table 3. Results of combined study for Japanese patients with SLE.

<table>
<thead>
<tr>
<th>rsID</th>
<th>Chr</th>
<th>Position (bp)</th>
<th>Cytoband</th>
<th>Gene</th>
<th>Allele</th>
<th>Stage</th>
<th>No. subjects</th>
<th>Allele 1 freq.</th>
<th>OR (95%CI)</th>
<th>P</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
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<td></td>
<td>1/2</td>
<td></td>
<td>Case</td>
<td>Control</td>
<td>Case</td>
<td></td>
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<tr>
<td>rs340630</td>
<td>4</td>
<td>88,177,419</td>
<td>4q21</td>
<td>AFF1</td>
<td>A/G</td>
<td>GWAS</td>
<td>891</td>
<td>3,383</td>
<td>0.56</td>
<td>0.51</td>
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<td></td>
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<td>Replication study 1</td>
<td>550</td>
<td>646</td>
<td>0.57</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Replication study 2</td>
<td>820</td>
<td>27,911</td>
<td>0.56</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Combined study</td>
<td>2,261</td>
<td>31,940</td>
<td>0.56</td>
</tr>
</tbody>
</table>

*Defined using gene expression data measured in lymphoblastoid B cell lines [28].

doi:10.1371/journal.pgen.1002455.t003
non-autosomal SNPs, and SNPs not shared between SLE cases and controls, were excluded. We excluded 7 closely related SLE cases in a 1st or 2nd degree of kinship based on identity-by-descent estimated using PLINK version 1.06 [41]. We then excluded 1 SLE cases and 1 controls whose ancestries were estimated to be distinct from East-Asian populations using PCA performed along with the genotype data of Phase II HapMap populations (release 24) [29] using EIGENSTRAT version 2.0 [42]. Subsequently, SNPs with minor allele frequencies <0.01 in SLE cases or controls, SNPs with exact P-values of Hardy-Weinberg equilibrium test <1.0×10^{-6} in controls, or SNPs with ambiguous cluster plots were excluded. Finally, 430,797 SNPs for 891 SLE cases and 3,384 controls were obtained. Genotyping of SNPs in replication studies was performed using TaqMan Assay or Illumina HumanHap610-Quad Genotyping BeadChip (Illumina, CA, USA).

Figure 3. Association of rs340630 with AFF1 expression. (A) Correlation between rs340630 genotypes and transcript levels of AFF1 (NM_001166693) in EBV-transfected cell lines (n = 62) stimulated with PMA. (B) Allele-specific quantification (ASTQ) of AFF1 transcripts. Allele specific-probes for rs340638 were used for quantification by qPCR. The ratios of A allele over G allele for the amounts of both cDNAs and DNAs were plotted in log scale for each cell line. (C) AFF1 expression in various tissues. Transcripts levels of AFF1 were quantified by qPCR and were normalized by GAPDH levels.
doi:10.1371/journal.pgen.1002455.g003
Association analysis of the SNPs

Association of SNPs in GWAS and replication studies were tested with Cochran-Armitage’s trend test. Combined analysis was performed with Mantel-Haenzel method. Associations of previously reported SLE susceptibility loci [3–18] were evaluated using the results of the GWAS. Genotype imputation was performed for non-genotyped SNPs using MACH version 1.0 [43] with Phase II HapMap East-Asian individuals as references [29], as previously described [44]. All imputed SNPs demonstrated imputation scores, R2g, >0.70.

eQTL study

We analyzed gene expression data previously measured in lymphoblastoid B cell lines from Phase II HapMap East-Asian individuals using Illumina’s human whole-genome expression array (WG-6 version 1) (accession number; GSE6536) [28]. Expression data were normalized across the individuals. We used BLAST to map 47,294 Illumina array probes onto human autosomal reference genome sequences (Build 36). We discarded probes matched with expectation values smaller than 0.01 to multiple loci, or for which there was polymorphic HapMap SNP(s) inside the probe. Then, 19,047 probes with exact matches to a unique locus with 100% identity and with a mean signal intensity greater than background were obtained. Genotype data of HapMap individuals were obtained for SNPs included in the GWAS. Associations of SNP genotypes (coded as 0, 1, and 2) with expression levels of each of the cis-eQTL probes (located within 600 kbp of SNPs) were evaluated using linear regression assuming additive effects of the genotypes on the expression levels. Considering the significant overlap between eQTL and genetic loci responsible for autoimmune diseases [24], we applied relatively less stringent multiple testing threshold of FDR Q-values<0.2 for the definition of eQTL SNPs that exhibited this threshold with any of the corresponding cis-eQTL probes were denoted as eQTL positive.

Selection of SNPs enrolled in the replication studies

In order to select SNPs for further replication studies, we firstly integrated the results of GWAS and eQTL study. SNPs that satisfied P<1.0×10^{-4} in GWAS, or the SNPs that satisfied 1.0×10^{-6}<P<1.0×10^{-3} in GWAS and denoted as eQTL positive, were selected. Among these, SNPs most significantly associated in each of the genomic loci and not included in the previously reported SLE susceptibility loci [3–18] were further evaluated.

Then, the results of the concurrently proceeding genome-wide scan for SLE in the Japanese subjects using a pooled DNA approach were referred (Tahira T et al. Presented at the 59th Annual Meeting of the American Society of Human Genetics, October 21, 2009). In the scan, DNA collected from 447 SLE cases and 680 controls of Japanese origin were pooled respectively, and SNP association signals in the pooled analysis (rank-based P<0.5) or was located within ±100 kbp of SNPs showing association signals in the pooled analysis (rank-based P<0.01), it would be selected. SNPs that satisfied P<1.0×10^{-6} in the combined study of GWAS and replication study 1 were further evaluated in replication study 2 (Figure 1).

Quantification of AFF1 expression

EBV-transformed lymphoblastoid cell lines (n=62) were established by Pharma SNP Consortium (Tokyo, Japan) using peripheral blood lymphocytes of Japanese healthy individuals. Cells were incubated for 2 h in medium alone (RPMI 1640 medium containing 10% FBS, 1% penicillin, and 1% streptomycin) or with 100 ng/ml PMA. Conditions for cell stimulation were optimized before the experiment as previously described [45]. Cells were then harvested and total RNA was isolated using an RNeasy Mini Kit (Qiagen) with DNase treatment. Total RNA (1 µg) was reverse transcribed using TaqMan Gold RT-PCR reagents with random hexamers (Applied Biosystems). Real-time quantitative PCR was performed in triplicate using an ABI PRISM 7900 and TaqMan gene expression assays (Applied Biosystems). Specific probes (Hs01089125_m1) for transcript of AFF1 (NM_001166693) were used. Expression of AFF1 in various tissues was also quantified using Premium Total RNA (Clontech). The data were normalized to GAPDH levels. GUS levels were also evaluated for internal control, and similar results were obtained. Correlation coefficient, R^2 between rs340630 genotypes and transcript levels of AFF1 was evaluated.

Allele-specific transcript quantification (ASTQ)

ASTQ of AFF1 in PSC cells was performed as previously described [46]. DNAs were extracted by using a DNeasy Kit (QIAGEN), RNA extraction and cDNA preparation were performed as described above. For PSC cells (n=17) that were heterozygous for both rs340630 (the landmark SNP of GWAS) and rs340638 (located in the 5’ untranslated region of AFF1 and in absolute LD with rs340630), expression levels of AFF1 were quantified by qPCR on an ABI Prism 7900 using a custom-made TaqMan MGB-probe set for rs340630. Primer sequences were 5’-CTAACCTGTGCGCAGGTGTTG-3’ and 5’-CCCGGGCGCATTTCTTGAG-3’. The probe sequences were 5’-VIC-GCGAACCGCAGCCCAAC TAMRA-3’ and 5’-FAM-CGCGACCGGGCGCCCCCAAT TAMRA-3’. Ct values of VIC and FAM were obtained for genomic DNA and cDNA samples after 40 cycles of real-time PCR. We also prepared genomic DNA of samples homozygous for each allele and mixed them at different ratios (2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2) to create a standard curve by plotting Ct values of VIC/FAM against the allelic ratio of VIC/FAM for each mixture. Using the standard curve, we calculated the allelic ratios for each genomic DNA and cDNA samples. We measured each sample in quadruplicate in one assay; tests were independently repeated twice.

Web resources

The URLs for data presented herein are as follows.
PLINK software, http://pngu.mgh.harvard.edu/~purcell/plink/index.shtml
International HapMap Project, http://www.hapmap.org
EIGENSTRAT software, http://genepath.med.harvard.edu/~reich/Software.htm
MACH and mach2qtl software, http://www.sph.umich.edu/csg/abecasis/MACH/index.html

Supporting Information

Figure S1 Principal component analysis (PCA) plot of the subjects. PCA plot of subjects enrolled in the GWAS for SLE. SLE cases and the controls enrolled in the GWAS are plotted based on
Figure S2: Quantile-Quantile plot (QQ-plot) of P-values in the GWAS for SLE. The horizontal axis indicates the expected log_{10}(P)-values. The vertical axis indicates the observed log_{10}(P)-values. The QQ-plot for the P-values of all SNPs that passed the quality control criteria is indicated in blue. The QQ-plot for the P-values after the removal of SNPs included in the previously reported SLE susceptibility loci is indicated in black. The gray line represents y = x. The SNPs for which the P-value was smaller than 1.0 × 10^{-15} are indicated at the upper limit of the plot.

Table S1: Basal characteristics of cohorts.

Table S2: Frequency of clinical characteristics of SLE in this GWAS.

Table S3: Distributions of eQTL positivity rates of the SNPs.

References


Table S4: Results of replication study 1 for Japanese patients with SLE.

Table S5: Results of replication studies 1 and 2 for Japanese patients with SLE.

Acknowledgments

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Author Contributions


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