Higher \textit{FKBP5}, \textit{COMT}, \textit{CHRNA5}, and \textit{CRHR1} allele burdens are associated with PTSD and interact with trauma exposure: implications for neuropsychiatric research and treatment

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**Objective:** The study aim was to assess the cumulative burden of polymorphisms located within four genetic loci previously associated with posttraumatic stress disorder (PTSD) among outpatients at risk for PTSD.

**Methods:** Diagnostic interviews were completed and DNA samples collected among 412 pain patients to determine if \textit{FKBP5} (rs9470080), \textit{COMT} (rs4680), \textit{CHRNA5} (rs16969968), and \textit{CRHR1} (rs110402) single nucleotide polymorphisms were cumulatively associated with increased risk for PTSD.

**Results:** In bivariate analyses, it was found that a count of specific PTSD risk alleles located within \textit{FKBP5}, \textit{COMT}, \textit{CHRNA5}, and \textit{CRHR1} genetic loci (allele range = 0–6, mean count = 2.92, standard deviation = 1.36) was associated with lifetime (t [409] = 3.430, \(P = 0.001\)) and early onset PTSD (t [409] = 4.239, \(P = 0.000028\)). In logistic regression, controlling for demographic factors, personality traits, and trauma exposures, this risk allele count remained associated with both lifetime (odds ratio = 1.49, \(P = 0.00158\)) and early onset PTSD (odds ratio = 2.36, \(P = 0.000093\)). Interaction effects were also detected, whereby individuals with higher risk allele counts and higher trauma exposures had an increased risk of lifetime PTSD (allele count \(\times\) high trauma, \(P = 0.026\)) and early onset PTSD (allele count \(\times\) high trauma, \(P = 0.016\)) in these logistic regressions. Those with no or few risk alleles appeared resilient to PTSD, regardless of exposure history.

**Conclusion:** A cumulative risk allele count involving four single nucleotide polymorphisms located within the \textit{FKBP5}, \textit{COMT}, \textit{CHRNA5}, and \textit{CRHR1} genes are associated with PTSD. Level of trauma exposure interacts with risk allele count, such that PTSD is increased in those with higher risk allele counts and higher trauma exposures. Since the single nucleotide polymorphisms studied encompass stress circuitry and addiction biology, these findings may have implications for neuropsychiatric research and treatment.

**Keywords:** posttraumatic stress disorder, genetic association study, single nucleotide polymorphism, risk alleles, trauma exposure, neuroticism, childhood adversity

**Introduction**

While studies suggest that most adults have experienced lifetime traumatic events, relatively few of them develop posttraumatic stress disorder (PTSD).\textsuperscript{1–3} Available twin and family studies indicate that PTSD is at least moderately heritable, with approximately 30% of variance accounted for by genetic factors.\textsuperscript{4} To date several genetic components for PTSD have been identified that may explain this risk.\textsuperscript{5–7} These include biologic pathways involving the hypothalamic-pituitary-adrenal (HPA), locus

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coeruleus-noradrenergic, and the limbic systems, among others.6,8–11 In the current study, genetic risk factors for PTSD were assessed among outpatients with chronic, nonmalignant pain, a condition often associated with PTSD.12

For the current study, four genetic markers were assessed using a cumulative risk allele model to test for an association with PTSD among outpatients, similar to what has been undertaken to predict complex genetic associations in other clinical areas.13 To assess PTSD, a validated questionnaire based on the Diagnostic and Statistical Manual of Mental Disorder, Fourth Edition was used.14,15 Extending previous research,9 single nucleotide polymorphisms (SNPs) located within the FK506 binding protein-5 (FKBP5), catechol-O-methyltransferase (COMT), cholinergic receptor nicotinic alpha-5 (CHRNA5), and the corticotropin-releasing hormone receptor-1 (CRHR1) gene clusters were specifically genotyped and these markers were assessed for cumulative risk for PTSD.

The COMT gene is associated with anxiety disorders, psychosis, depression, and other conditions involving catecholamine pathway regulation and has recently been associated with PTSD.9,18,19 The FKBP5 gene regulates glucocorticoid receptor sensitivity, is functionally involved in HPA axis activity, and is associated with PTSD.5,6,9,20 The CHRNA gene cluster, which encodes components of the nicotinic acetylcholine receptor, is associated with nicotine dependence and cigarette smoking,21,22 substance misuse,23 and recently PTSD.9 The CRHR1 gene is a polypeptide hormone and neurotransmitter involved in corticotropin-releasing hormone activity associated with the stress response. Studies suggest that this gene also regulates HPA axis function and is associated with the impact of traumatic stress exposure and PTSD.20,24

Methods

Subjects
Study subjects were adult outpatients (≥18 years old) who were prescribed pain medications for nonmalignant pain for ≥4 months.14,22 Chronic pain patients typically have a high prevalence of PTSD.25,26 The mean age of patients was 55 years old (standard deviation = 13.4) and the prevalence of lifetime PTSD was 15% (95% confidence interval [CI] = 11.7–18.1). The sample was randomly selected from among a population of chronic pain outpatients identified by query of the electronic health records of the Geisinger Clinic, an integrated health system that serves residents of 40 central and northeastern Pennsylvania counties.14 Geisinger’s ambulatory clinics have used the Epic (Epic Systems Corporation, Verona, WI) outpatient electronic health record system since 2001. With patient consent, trained and supervised interviewers administered structured diagnostic telephone interviews from August 2007 through November 2008.

Phenotypic and confounding measures

Study interviewers administered diagnostic surveys using instruments used in past research.2,16,17 To meet criteria for lifetime PTSD, patients had to meet the full diagnostic criteria for PTSD, known as the “A through F” criteria.2,15 These criteria include experiencing intense fear (criterion A), re-experiencing the event (criterion B), avoidance of stimuli associated with the event (criterion C), experiencing increased arousal (criterion D), experiencing symptoms for a month or more (criterion E), and experiencing psychological distress or impairment (criterion F). To be diagnosed with early onset PTSD, the patient had to meet the A–F diagnostic criteria for PTSD before the age of 35 years. Research typically suggests that early onset PTSD likely has greater impact on trauma victims.27,28 Over half (53%) of the PTSD cases in the current study met this early onset definition. Research instruments relevant to childhood adversity, lifetime trauma exposure, and self-esteem were also administered.17,29–31 To assess neuroticism, also a risk factor for PTSD,32 the NEO Five-Factor Inventory was used.33

The childhood adversity scale used was the Adverse Childhood Experiences scale, a widely used measure of childhood adversity with good reported reliability and validity.29,30,34 Cronbach’s alpha for the Adverse Childhood Experiences scale in the current study was 88. The trauma scale used was a measure that has been extensively used in past trauma research and has been shown to have excellent predictive validity.16,17,35 In the current study, this measure consisted of a count of the number of traumatic events (eg, combat exposure, sexual assault, major disaster) that the person experienced in his/her lifetime (range 0–9, mean = 2.19, standard deviation = 2.0). Self-esteem was measured by the Rosenberg Self-Esteem Scale, a widely used construct to measure self-esteem.31,36 In the current study, Cronbach’s alpha was 80 for this scale. The NEO Five-Factor Inventory is a personality measure widely used in neuropsychiatric research.33,37,38 This scale is reported to have good reliability and validity.37,38 Cronbach’s alpha for the scales used in the NEO are good, typically between 0.76–0.89.39

Given that the current study population was drawn from a sample of pain patients, the study results were also adjusted for prescription opioid dependence, level of pain impairment, and the number of opioid prescriptions received as
potential confounders. Opioid dependence was based on whether the subject met criteria for Diagnostic and Statistical Manual of Mental Disorder, Fourth Edition drug dependence and was based on a diagnostic interview. Pain assessment was based on the Brief Pain Inventory, a widely used and validated instrument. The number of opioid prescriptions received over the past 3 years was based on electronic health record data. Finally, to potentially account for population stratification, the study results were also adjusted for ancestry status, based on country of origin, coded as Northern European, Eastern European, Southern European, and other. Non-Caucasians were excluded from these analyses. This study was approved by the Geisinger Clinic’s Institutional Review Board.

DNA collection and genotyping

Following the study interview, buccal swab kits were mailed to consenting adults. Altogether, 412 returned the buccal swab kit with adequate DNA for the current analyses. Two subjects were identified as non-Caucasian and were not included in the current study analyses, as noted. The candidate genes studied (and corresponding SNPs) were: COMT (rs4680), FKBPs (rs9470080), CHRNA5 (rs16969968), and CRHR1 (rs110402). The SNPs for the four target loci were originally selected using linkage disequilibrium tagging with consideration of prior evidence and functional annotation. For each gene, the location of the main association signals related to PTSD were determined from the relevant literature. The linkage disequilibrium structure of the gene in the HapMap Caucasian sample (release 23a; http://www.hapmap.org) was then examined using the Gabriel algorithm. The algorithm of de Bakker implemented in the software HaploView 4.0 (Daly Lab, Broad Institute, Cambridge, MA) was then used to select tagged SNPs for the target block in each gene. The Gabriel algorithm delineates boundaries of genomic markers identified as haplotype blocks with little evidence for historical recombination, within which only a few common haplotypes are observed and that can be tagged for association analysis using unsaturated SNP subsets. The de Bakker approach selects tags from empirical data based on linkage disequilibrium to maximize the cost-effectiveness of using a limited number of typed SNPs in a locus.

Genotyping was performed on an Applied BioSystems 7500 Real-Time Polymerase Chain Reaction System using TaqMan® kits (Applied BioSystems, Foster City, CA), following the manufacturer’s protocols. Quality control measures included visual inspection of the allelic discrimination plots, monitoring concordance of cross-plated duplicate pairs, monitoring the overall call rate, and monitoring agreement with Hardy–Weinberg expectations.

Statistical analyses

Based on previous research, a bivariate association with PTSD was tested for the four target SNPs in the current study and each of these was found to be significant (P < 0.05). A cumulative risk allele model that included these four SNPs was then developed, as has been done in other clinical areas. As suggested, each of these target SNPs had been associated with PTSD in previous reports. For each SNP studied, as previously discussed, an additive coding scheme (ie, subjects assigned zero, one, or two according to the number of copies of the minor allele) was tested followed by a dominant/recessive coding scheme (ie, carriers and homozygotes for the tested allele assigned a value of one, versus homozygotes for the alternate allele assigned a value of zero) if the additive model was not significant. Only one SNP tested was reduced to a dominant/recessive model (Table 1). A count of alleles across these loci resulted in a risk score ranging from 0–6 (mean = 2.92, standard deviation = 1.36). For descriptive analyses, chi-squared tests were used to assess the associations between the main variables of interest and PTSD status (Table 2). In addition, independent t-tests were also used to assess the bivariate association between risk allele counts and key exposure variables, which included trauma exposure,

| SNP       | Gene   | Chromosome (map location) | MAF (minor/common) | Functional annotation | HWE P value |
|-----------|--------|---------------------------|--------------------|-----------------------|-------------|
| rs16969968 | CHRNA5 | 15 (78882925)             | 35.0% (A/G)        | Missense (D→N)        | 0.0279      |
| rs9470080 | FKBPs  | 6 (35646435)              | 33.0% (T/C)        | Intron                | 0.7404      |
| rs4680    | COMT   | 22 (19951271)             | 49.5% (G/A)        | Missense (V→M)        | 0.9709      |
| rs110402  | CRHR1  | 17 (43880047)             | 42.4% (A/G)        | Intron                | 0.4333      |

Notes: *Additive model coded 0, 1, 2 for risk allele; **dominant model coded 0, 1 for the risk allele.

Abbreviations: HWE, Hardy–Weinberg equilibrium; MAF, minor allele frequency; NCBI, National Center for Biotechnology Information (Bethesda, MD); SNP, single nucleotide polymorphism.
Table 2: Lifetime posttraumatic stress disorder and early onset posttraumatic stress disorder by study variables

| Study variables          | % total (N) | Lifetime PTSD | Early onset PTSD | P value | P value |
|--------------------------|-------------|---------------|------------------|---------|---------|
|                          | % yes (N)   | % no (N)      | % yes (N)        | % no (N)|         |
| Sex                      |             |               |                  |         |         |
| Male                     | 30.2 (152)  | 9.9 (15)      | 4.6 (7)          | 95.4 (145) | 0.044  |
| Female                   | 68.9 (351)  | 16.8 (59)     | 9.1 (32)         | 90.9 (319) | 0.082  |
| Age (years)              |             |               |                  |         |         |
| 18–44                    | 17.3 (87)   | 25.3 (22)     | 24.1 (21)        | 75.9 (66) | <0.0001|
| 45–64                    | 58.3 (293)  | 15.4 (45)     | 5.5 (16)         | 94.5 (277) | <0.0001|
| 65+                      | 24.5 (123)  | 5.7 (7)       | 1.6 (2)          | 98.4 (121) |        |
| Married                  |             |               |                  |         |         |
| No                       | 38.2 (192)  | 19.8 (38)     | 10.9 (21)        | 89.1 (171) | 0.036  |
| Yes                      | 61.8 (311)  | 11.6 (36)     | 5.8 (18)         | 94.2 (293) |        |
| High school education or less |       |               |                  |         |         |
| No                       | 50.1 (252)  | 15.5 (39)     | 9.5 (24)         | 90.5 (228) | 0.137  |
| Yes                      | 49.9 (251)  | 13.9 (35)     | 6.0 (15)         | 94.0 (236) |        |
| Income less than $30,000 |             |               |                  |         |         |
| No                       | 57.5 (289)  | 11.4 (33)     | 5.5 (16)         | 94.5 (273) | 0.031  |
| Yes                      | 42.5 (214)  | 19.2 (41)     | 10.7 (23)        | 89.3 (191) |        |
| High trauma exposure     |             |               |                  |         |         |
| No                       | 78.5 (395)  | 10.9 (43)     | 4.3 (17)         | 95.7 (378) | <0.0001|
| Yes                      | 21.5 (108)  | 28.7 (31)     | 20.4 (22)        | 79.6 (86) |        |
| High childhood adversity |             |               |                  |         |         |
| No                       | 73.2 (368)  | 10.1 (37)     | 3.8 (14)         | 96.2 (354) | <0.0001|
| Yes                      | 26.8 (135)  | 27.4 (37)     | 18.5 (25)        | 81.5 (110) |        |
| High neuroticism         |             |               |                  |         |         |
| No                       | 78.3 (394)  | 10.4 (41)     | 6.1 (24)         | 93.9 (370) | 0.008  |
| Yes                      | 21.7 (109)  | 30.3 (33)     | 13.8 (15)        | 86.2 (94) |        |
| High self-esteem         |             |               |                  |         |         |
| No                       | 80.1 (403)  | 17.4 (70)     | 8.9 (36)         | 91.1 (367) | 0.047  |
| Yes                      | 19.9 (100)  | 4.0 (4)       | 3.0 (3)          | 97.0 (97) |        |

Abbreviation: PTSD, posttraumatic stress disorder.

Results

The bivariate analysis confirmed that all four target SNPs were associated with lifetime PTSD (P < 0.05), including FKBP5 (rs9470080), COMT (rs4680), CHRNA5 (rs16969968), and CHRR1 (rs110402) SNPs. For each of these target SNPs, Table 1 shows the chromosomal location, minor allele frequency, functional annotation, and Hardy–Weinberg equilibrium results. All four SNPs studied met expectations for Hardy–Weinberg equilibrium (P > 0.025). Table 2 shows the association between lifetime and early onset PTSD and the main study variables. As can be seen, lifetime PTSD is associated with female sex, younger age, being unmarried, having lower household income, having higher trauma exposure, having higher childhood adversity, having higher neuroticism, and having lower self-esteem (all P values <0.05).

Table 3 shows the unadjusted risk allele count results by PTSD status and key study variables. The prevalence of lifetime PTSD in the study was 14.7% (95% CI = 11.7–18.1) and the prevalence of early onset PTSD was 7.6% (95% CI = 5.1–10.7) (Table 3). As can be seen, both lifetime (P = 0.001) and early onset (P = 0.000028) PTSD were

Adversity exposure, neuroticism level, self-esteem, as well as PTSD status (Table 3). Next, multivariate logistic regressions were used to test for an association of genetic risk allele count with PTSD status, controlling for potential confounding (Table 4).22,27 Gene × environmental exposure interaction effects were specifically tested for (Table 5), since these have been previously reported for some of these loci.25,28 For these interaction assessments, lifetime trauma and childhood adversity were classified as high versus not, based on the upper quintile or quartile range for lifetime trauma and childhood adversity, respectively. Specific gene × environment interaction effects were statistically evaluated by use of a cross-product term for risk allele-count × trauma exposure (or childhood adversity) in multivariate logistic regressions that included the main effects (ie, risk allele count and the respective environmental exposure) and predicted PTSD status. As suggested, given the current study population, prescription opioid dependence, pain impairment, and the number of opioid prescriptions received were also assessed as potential confounders as a final regression step. For data analyses, Stata® version 11.2 (StataCorp LP, College Station, TX) was used.
Table 3 Mean risk allele counts by posttraumatic stress disorder status and key study variables (mean risk allele count = 2.92, standard deviation = 1.36)

| Study variables | Risk allele counts | t-test | Difference | P value |
|-----------------|--------------------|--------|------------|---------|
| Lifetime PTSD*  | Mean (n)           |        |            |         |
| No              | 2.83 (352)         | –      | –          | –       |
| Yes             | 3.47 (59)          | 3.430  | 0.648      | 0.001   |
| Early onset PTSD** | Mean (n)         |        |            |         |
| No              | 2.84 (382)         | –      | –          | –       |
| Yes             | 3.93 (29)          | 4.239  | 1.09       | 0.000028|
| High trauma     | No (ref)           | –      | –          | –       |
| Yes             | 2.90 (324)         | 0.442  | 0.073      | 0.659   |
| High adversity  | No (ref)           | –      | –          | –       |
| Yes             | 2.98 (87)          | 0.704  | 0.116      | 0.482   |
| High neuroticism| No (ref)           | –      | –          | –       |
| Yes             | 2.92 (323)         | –      | –          | –       |
| High self-esteem| No (ref)           | –      | –          | –       |
| Yes             | 3.01 (86)          | 0.704  | 0.116      | 0.482   |

Notes: *Prevalence of lifetime posttraumatic stress disorder = 14.7% (95% confidence interval = 11.7–18.1); †prevalence of early onset posttraumatic stress disorder = 7.6% (95% confidence interval = 5.1–10.7).

Abbreviation: PTSD, posttraumatic stress disorder.

associated with higher risk allele counts. Trauma exposure, childhood adversity, neuroticism, and self-esteem were not associated with risk allele counts (all P values >0.05).

Table 4 presents the multivariate logistic regression results for lifetime and early onset PTSD. As can be seen, after controlling for demographic factors, trauma exposures and psychological traits (ie, neuroticism and self-esteem), risk allele count was significant for lifetime PTSD (odds ratio [OR] = 1.49, P = 0.00158). Noteworthy is that high trauma exposure (P = 0.049) and high neuroticism (P = 0.0003) were significant in this adjusted lifetime PTSD model. For early onset PTSD, the multivariate logistic regression results were highly significant (OR = 2.36, P = 0.000093). In contrast to lifetime PTSD, significant variables in this early onset model included high trauma exposure (P = 0.0011) and high childhood adversity (P = 0.0074). These logistic regression data suggest that those with six or more risk alleles have about nine times greater risk of lifetime PTSD (6 × 1.49 = 9) and that those with six or more risk alleles have about 14 times greater risk of early onset PTSD (6 × 2.36 = 14) than those with no risk alleles, respectively (Table 4).

Following assessment of main effect models, interaction effects were evaluated for allele count × high trauma and allele count × high adversity exposure for both lifetime and early onset PTSD (Table 5). These interaction effects were significant for risk allele count × high trauma exposure for both lifetime (OR = 2.05, P = 0.026) and early onset PTSD (OR = 3.47, P = 0.016) (Table 5). These interactions suggest that individuals with higher risk allele counts and higher trauma exposures had an increased risk of PTSD. However, the interaction effect for risk allele count × high childhood adversity was not significant in either the lifetime or early onset PTSD model (available upon request).

Figure 1 shows the prevalence of both lifetime and early onset PTSD by risk allele burden. As seen, those with less than two risk alleles have a low prevalence of PTSD. By comparison, those with four or more risk alleles have a prevalence of lifetime PTSD of more than 20%. These data

Table 4 Multivariate logistic regressions predicting lifetime and early onset posttraumatic stress disorder from risk allele count, controlling for key risk factors and potential confounders

| Study variables | Lifetime PTSD† | Early onset PTSD‡ |
|-----------------|---------------|------------------|
|                 | OR (95% CI)   | P value          | OR (95% CI)   | P value |
| Risk allele count (0–6)* | 1.49 (1.16–1.90) | 0.00158 | 2.36 (1.53–3.62) | 0.000093 |
| High trauma     |               |                  |               |         |
| No (ref)        | 1.00          | –                | 1.00          | –       |
| Yes             | 2.03 (1.00–4.11) | 0.049  | 5.21 (1.93–14.09) | 0.0011  |
| High adversity  |               |                  |               |         |
| No (ref)        | 1.00          | –                | 1.00          | –       |
| Yes             | 1.52 (0.79–2.92) | 0.209  | 3.90 (1.44–10.55) | 0.0074  |
| High neuroticism|               |                  |               |         |
| No (ref)        | 1.00          | –                | 1.00          | –       |
| Yes             | 3.31 (1.72–6.37) | 0.0003 | 1.74 (0.64–4.74) | 0.282   |
| High self-esteem|               |                  |               |         |
| No (ref)        | 1.00          | –                | 1.00          | –       |
| Yes             | 0.23 (0.05–1.03) | 0.055  | 0.94 (0.18–4.84) | 0.939   |

Notes: *Risk allele count coded as a continuous variable, coded 0–6; †logistic regression model includes risk allele count, trauma exposure, childhood adversity, neuroticism, and self-esteem, plus age (in years), sex, income, and marital status as covariates.

Abbreviations: CI, confidence interval; OR, odds ratio; PTSD, posttraumatic stress disorder.
suggest that those with no or few risk alleles may be resilient to PTSD, regardless of environmental exposures, since these exposures were not associated with allele burden (Table 3) or with significant confounding of the association between allele count and PTSD (Table 4). This suggests that the main exposures known to cause PTSD – psychological trauma – did not vary by risk allele count. However, those with higher risk allele counts and high trauma exposure have an increased risk of PTSD (Table 5), indicating that a gene × environmental effect is present for risk allele count by level of trauma exposure.

As suggested, since the study population included Caucasian pain patients on pain medications, pain status, drug dependence status, the number of prescription orders for pain medicines were also controlled for, but these variables had little impact on the final regression results. Based on previous research, since a dominant model for SNP marker rs9470080 (FKBP5) – and not the other three markers – was used, a risk allele model that included all four SNPs was also assessed as additive risk allele markers (ie, all four SNPs coded zero, one, or two). This additive model produced similar results in the logistic regressions. Finally, ancestry status was also entered into the final logistic regression models and this adjustment also made little difference.

**Discussion**

Examination of risk allele counts by PTSD status, as coded in the regression models, suggested that the “A” allele of rs16969968 (CHRNA5) and rs4680 (COMT), the “T” allele of rs9470080 (FKBP5), and the “G” allele of rs110402 (CRNR1) are more common among PTSD cases than non-PTSD cases. Thus, this study confirmed that SNP markers rs16969968(A), rs9470080(T), rs4680(A), and rs110402(G) were each individually associated with PTSD. When these SNP markers were combined into a cumulative risk allele model (Table 3), the bivariate t-test results were significant for both lifetime (P = 0.001) and early onset PTSD (P = 0.000028). In multivariate analyses controlling for potential confounders, both lifetime (OR = 1.49, P = 0.00158) and early onset PTSD (OR = 2.36, P = 0.000093) remained significant. Interactions were also detected for risk allele count × trauma exposure for both lifetime (P = 0.026) and early onset PTSD (P = 0.016).

**Table 5** Multivariate logistic regression interactions for lifetime and early onset posttraumatic stress disorder showing risk allele count × high trauma exposure effect

| Study variables                        | Lifetime PTSD† | Early onset PTSD† |
|----------------------------------------|----------------|------------------|
|                                        | OR (95% CI)    | P value          |
| Risk allele count†                     | 1.24 (0.94–1.65) | 0.131            |
| High trauma**                          | 0.19 (0.02–1.79)   | 0.146            |
| Risk allele count × high trauma        | 2.05 (1.09–3.87)   | 0.026            |

**Notes:** †Risk allele count coded as a continuous variable, coded 0–6; **high trauma coded as binary variable, coded 0, 1; †logistic regression model includes risk allele count, trauma exposure, childhood adversity, neuroticism, and self-esteem, plus age (in years), sex, income, and marital status as covariates. The interaction effect (ie, risk allele count × trauma exposure) has been added to this model.

**Abbreviations:** CI, confidence interval; OR, odds ratio; PTSD, posttraumatic stress disorder.

![Figure 1](https://example.com/figure1.png)

**Figure 1** Prevalence of lifetime posttraumatic stress disorder and early onset posttraumatic stress disorder by risk allele burden.

**Abbreviation:** PTSD, posttraumatic stress disorder.
The final cumulative risk model suggests that the risk for lifetime PTSD was about nine times higher among those with six or more risk alleles (1.49 × 6 = 9), compared to those with no risk alleles. For early onset PTSD, this risk was about 14 times higher among those with six or more risk alleles (2.36 × 6 = 14).

FKBP5 polymorphisms are known to regulate the cortisol-binding affinity and nuclear translocation of the glucocorticoid receptor and polymorphisms at the FKBP5 locus have been reported to interact with exposure to child adversity in predicting PTSD.\(^5\)\(^4\)\(^8\) COMT polymorphisms have been found to affect fear extinction and are thought to play a role in the etiology of anxiety disorders.\(^9\)\(^19\)\(^40\) The CHRNA5 gene has been associated with smoking and nicotine dependence.\(^21\)\(^22\) PTSD is known to be associated with cigarette smoking.\(^50\) This locus has recently been associated with PTSD and is likely involved in mammalian fear circuitry.\(^9\) Research suggests that the CRHR1 gene regulates HPA axis function in conjunction with exposure to early life trauma.\(^20\) In addition, corticotropin-releasing hormone is thought to play a role in the pathophysiology of stress-related psychiatric disorders, such as major depressive disorder and PTSD.\(^24\) It has been suggested that corticotropin-releasing hormone contributes to alterations in memory formation in PTSD cases and that this hormone influences hippocampal regulation of the HPA axis.\(^24\) Note that the assignment of risk alleles for the SNP variants examined in the current study agree with prior findings for the FKBP5, CRHR1, and COMT genetic variants.\(^5\)\(^5\)\(^1\)\(^5\)\(^1\)\(^5\)\(^1\)\(^5\)\(^1\)\(^5\)\(^1\)\(^5\)\(^1\) A 2011 paper, based on this same cohort,\(^6\) was the first to associate a CHRNA5 genetic variant with PTSD, so the risk allele assignment in the current paper would be consistent with that earlier paper.

It is noteworthy that research suggests that PTSD is associated with an increased prevalence of chronic health conditions, including cardiovascular disease, rheumatoid arthritis, and other chronic diseases.\(^54\)\(^60\) Studies suggest that PTSD may result in inflammatory injuries through overactivation of the HPA and sympathetic-adrenal-medullary stress axes, subsequently followed by hypocortisolism related to molecular downregulation of these systems.\(^54\)\(^61\)\(^62\) Epigenetic-related phenomena are also suspected.\(^63\)\(^64\) Consistent with these findings, current research suggests that low-grade systemic inflammatory activity is common in PTSD.\(^65\)\(^66\) This PTSD-disease link also could be related to adverse health behaviors, such as cigarette smoking and substance misuse related to self-regulation of aversive psychological states brought on by PTSD.\(^69\)\(^70\)

Study limitations for this research include the fact that the interview data were based on self-report, the total sample size was limited, and the study participants were more often female and drawn from a pain population. Also, multiple comparisons were not adjusted for and population stratification using genetic methods were not taken into account, although final regression results were adjusted for reported ancestry and all non-Caucasians were eliminated from the analyses to control for stratification. These factors may have biased the results and could limit study generalization. Also, the total number of PTSD cases in the study was limited (n = 59). Thus, the findings will require further replication.

The current research suggests that FKBP5, COMT, CHRNA5, and CRHR1 genetic loci involving biologic pathways encompassing inflammatory mechanisms, nicotine dependence, substance misuse, sleep regulation, and fear circuitry, among others, are associated with PTSD and interact with levels of trauma exposure.\(^7\) These genetic loci seem worthy of research related to the behavioral genetics of PTSD as well as related to chronic disease onset. For example, researchers have reported that CHRNA gene is associated with lung cancer.\(^7\) This gene was also recently associated with cigarette smoking and nicotine dependence.\(^23\) Thus, the causal pathway for lung cancer involving these loci appears to involve nicotine addiction associated with alterations in nervous system molecular biology. Without this compulsive addiction behavior, there would likely be insufficient exposure to cigarette smoke to result in lung cancer for most individuals.

Similarly, the genetic components involved in PTSD, including the FKBP5, COMT, CHRNA5, and CRHR1 genes, may be associated with the pathophysiology of specific diseases following PTSD onset. Recently it was reported that CHRNA was not only associated with lung cancer but also with peripheral arterial disease.\(^24\) PTSD has also been associated with metabolic syndrome.\(^22\) Since the risk alleles studied appear to encompass multiple, interrelated disease pathways, these genetic markers may have research implications for neuropsychiatric research and treatment. The absence of PTSD among those with no or few risk alleles is intriguing and also worthy of investigation. The authors suspect that genetic resilience, in this case the absence of PTSD risk alleles, may also be associated with chronic disease resilience, but further research is required to confirm this hypothesis.

Previous presentation
Preliminary results from this study were presented at: The 31st Annual Anxiety Disorders Association of America Conference, New Orleans, LA, March 25, 2011.
Acknowledgments

Support for this study was provided in part by the Geisinger Clinic Research Fund (Grant No TRA-015) and the National Institute of Mental Health (Grant No R21-MH-086317) to Dr Boscarno.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Kessler RC, Sonnega A, Bromet E, Hughes M, Nelson CB. Posttraumatic stress disorder in the National Comorbidity Survey. Arch Gen Psychiatry. 1995;52(12):1048–1060.
2. Boscarno JA, Adams RE. PTSD onset and course following the World Trade Center disaster: findings and implications for future research. Soc Psychiatry Psychiatr Epidemiol. 2009;44(10):887–898.
3. Breslau N, Kessler RC, Chilcoat HD, Schultz LR, Davis GC, Andreski P. Trauma and posttraumatic stress disorder in the community: the 1996 Detroit Area Survey of Trauma. Arch Gen Psychiatry. 1998;55(7):626–632.
4. Stein MB, Jang KL, Taylor S, Vernon PA, Livesley WJ. Genetic and environmental influences on trauma exposure and posttraumatic stress disorder symptoms: a twin study. Am J Psychiatry. 2002;159(10):1675–1681.
5. Binder EB, Bradley RG, Liu W, et al. Association of FKBP5 polymorphisms and childhood abuse with risk of posttraumatic stress disorder symptoms in adults. JAMA. 2008;299(11):1291–1305.
6. Koenen KC. Genetics of posttraumatic stress disorder: review and recommendations for future studies. J Trauma Stress. 2007;20(5):737–750.
7. Nemeroff CB, Bremner JD, Foa EB, Mayberg HS, North CS, Stein MB. Association of FKBP5, COMT and CHRNA5 polymorphisms with PTSD among outpatients at risk for PTSD. Depression Anxiety. 2011;34(2):101–108.
8. Phifer J, Skelton K, Weiss T, et al. Voltage-sensitive dye imaging demonstrates an enhancing effect of corticotropic-releasing hormone on neuronal activity propagation through the hippocampal formation. J Psychiatr Res. 2011;45(2):256–261.
9. Beck JG, Clapp JD. A different kind of co-morbidity: understanding posttraumatic stress disorder and chronic pain. Psychiatr Clin North Am. 2011;34(2):223–230.
10. Kessler RC, Wang PS. The descriptive epidemiology of commonly occurring mental disorders in the United States. Annu Rev Public Health. 2008;29:115–129.
11. Spinelli S, Chefer S, Suomi SJ, Higley JD, Barr CS, Stein E. Early-life stress induces long-term morphologic changes in primate brain. Arch Gen Psychiatry. 2009;66(6):658–665.
12. Dong M, Giles WH, Felitti VJ, et al. Insights into causal pathways for ischemic heart disease: adverse childhood experiences study. Circulation. 2004;110(13):1761–1766.
13. Felitti VJ, Anda RF, Nordenberg D, et al. Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. The Adverse Childhood Experiences (ACE) Study. Am J Prev Med. 1998;14(4):245–258.
14. Rosenberg M. Conceiving the Self. New York, NY: Basic Books; 1979.
15. Cox BJ, MacPherson PS, Enns MW, McWilliams LA. Neuroticism and self-criticism associated with posttraumatic stress disorder in a nationally representative sample. Behav Res Ther. 2004;42(1):105–114.
16. Costa PT Jr, Widiger TA, editors. Personality Disorders and the Five-Factor Model of Personality. 2nd ed. Arlington, VA: American Psychological Association; 2002.
17. Resnick HS, Kilpatrick DG, Dansky BS, Saunders BE, Best CL. Prevalence of civilian trauma and posttraumatic stress disorder in a representative national sample of women. J Consult Clin Psychol. 1993;61(6):984–991.
18. Craddock N, Owen MJ, O’Donovan MC. The catechol-O-methyl transferase (COMT) gene as a candidate for psychiatric phenotypes: evidence and lessons. Mol Psychiatry. 2006;11(5):446–458.
19. Montag C, Buchholtz JW, Hartmann P, et al. COMT genetic variation affects fear processing: psychophysiological evidence. Behav Neurosci. 2008;122(4):901–909.
20. Gillespie CF, Phifer J, Bradley B, Ressler KJ. Risk and resilience: genetic and environmental influences on development of the stress response. Depress Anxiety. 2009;26(11):984–992.
21. Spitz MR, Amos CI, Dong Q, Lin J, Wu X. The CHRNA5-A3 region on chromosome 15q24–25.1 is a risk factor both for nicotine dependence and for lung cancer. J Natl Cancer Inst. 2008;100(21):1552–1556.
22. Hoge CW, Castro CA, Messer SC, et al. Mental health outcomes of U.S. veterans of the Iraq and Afghanistan wars. N Engl J Med. 2006;356(10):1092–1099.
Taylor MD, Whiteman MC, Fowkes GR, Lee AJ, Allerhand M, Deary IJ. Five Factor Model personality traits and all-cause mortality in the Edinburgh Artery Study cohort. *Psychosom Med*. 2009;71(6):631–641.

Costa PT Jr, McCrae RR. Revised NEO Personality Inventory (NEO-PI-R) and NEO Five Factor Inventory (NEO-FFI): Professional Manual. Lutz, FL: Psychological Assessment Resources Inc; 1992.

Cleeland CS, Ryan KM. Pain assessment: global use of the Brief Pain Inventory. *Ann Acad Med Singapore*. 1994;23(2):129–138.

Tan G, Jensen MP, Thornby JJ, Shanti BF. Validation of the Brief Pain Inventory for chronic nonmalignant pain. *J Pain*. 2004;5(2):133–137.

Ziegler A, Konig IR. A Statistical Approach to Genetic Epidemiology. 2nd ed. Weinheim: Wiley-VCH; 2010.

Gabriel SB, Schaffner SF, Nguyen H, et al. The structure of haplotype blocks in the human genome. *Science*. 2002;296(5576):2262–2229.

de Bakker PI, Yelenksy R, Pe’er I, Gabriel SB, Daly MJ, Altshuler D. Efficiency and power in genetic association studies. *Nat Genet*. 2005;37(11):1217–1223.

Strachan T, Read AP. *Human Molecular Genetics*. 4th ed. New York, NY: Garland Science; 2011.

Zheng SL, Sun J, Wiklund F, et al. COMT, PTSD, and increased smoking following hurricane exposure in an epidemiologic sample. *Neuropsychopharmacology*. 2010;35(8):1684–1692.

Amstadter AB, Nugent NR, Koenen KC, et al. Association between childhood maltreatment and neuroticism by the corticotropin–reactivity. *Biol Psychiatry*. 2009;66(7):681–685.

Thomas DC. *Statistical Methods in Genetic Epidemiology*. New York, NY: Oxford University Press; 2004.

Xie P, Kranzler HR, Poling J, et al. Interaction of FKBP5 with cortical progesterone receptor in alcoholics. *Psychosom Med*. 2011;73(4):408–410.

Fu SS, McFall M, Saxon AJ, et al. Posttraumatic stress disorder, cumulative life stress, and physical health among Israeli veterans twenty years after exposure to combat. *Soc Sci Med*. 2008;67(6):1257–1277.

O’Toole BJ, Catts SV. Trauma, PTSD, and physical health: an epidemiological study of Australian Vietnam veterans. *J Psychosom Res*. 2008;64(1):33–40.

Ahmadi N, Hajsadeghi F, Mirshkarlo HB, Budoff M, Yehuda R, Ebrahimi R. Post-traumatic stress disorder, coronary atherosclerosis, and mortality. *Am J Cardiol*. 2011;108(1):29–33.

Boscarino JA. Posttraumatic stress disorder and physical illness: results from clinical and epidemiologic studies. *Ann N Y Acad Sci*. 2004;1032:141–153.

Heim C, Ehlert U, Hellhammer DH. The potential role of hypocortisolism in the pathophysiology of stress-related bodily disorders. *Psychoneuroendocrinology*. 2000;25(1):1–35.

Smith AK, Conneely KN, Kilaru V, et al. Differential immune system DNA methylation and cytokine regulation in post-traumatic stress disorder. *Am J Med Genet B Neuropsychiatr Genet*. 2011;156B(6):700–708.

Uddin M, Aiello AE, Wildman DE, et al. Epigenetic and immune function profiles associated with posttraumatic stress disorder. *Proc Natl Acad Sci U S A*. 2010;107(20):9470–9475.

Gander ML, von Kanel R. Myocardial infarction and post-traumatic stress disorder: frequency, outcome, and atherosclerotic mechanisms. *Ear J Cardiovasc Prev Rehabil*. 2006;13(2):165–172.

Spitzer C, Barnow S, Volzke H, et al. Association of posttraumatic stress disorder with low-grade elevation of C-reactive protein: evidence from the general population. *J Psychiatr Res*. 2010;44(1):15–21.

von Kanel R, Hepp U, Kraemer B, et al. Evidence for low-grade systemic proinflammatory activity in patients with posttraumatic stress disorder. *J Psychiatr Res*. 2007;41(9):744–752.

Boscarino JA. Vietnam veterans, postwar experiences and health outcomes. In: Fink G, editor. *Encyclopedia of Stress*, Volume 3. 2nd ed. San Diego, CA: Academic Press; 2007:830–838.

Boscarino JA, Kirchner HL, Hoffman SN, Sartorius J, Adams RE, PTSD and alcohol use after the World Trade Center attacks: a longitudinal study. *J Trauma Stress*. 2011;24(5):515–525.

Vlahov D, Galea S, Resnick H, et al. Increased use of cigarettes, alcohol, and marijuana among Manhattan, New York, residents after the September 11th terrorist attacks. *Am J Epidemiol*. 2002;155(11):988–996.

Hung RJ, McKay JD, Gaborieau V, et al. A susceptibility locus for lung cancer maps to nicotinic acetylcholine receptor subunit genes on 15q25. *Nature*. 2008;452(7187):633–637.

Weiss T, Skelton K, Pfifer J, et al. Posttraumatic stress disorder is a risk factor for metabolic syndrome in an impoverished urban population. *Gen Hosp Psychiatry*. 2011;33(2):135–142.