Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

HHS Public Access

Author manuscript

J Clin Psychiatry. Author manuscript; available in PMC 2016 June 07.

Published in final edited form as:

J Clin Psychiatry. 2015 November ; 76(11): 1556–1563. doi:10.4088/JCP.14m09395.

Inflammatory Markers among Adolescents and Young Adults with Bipolar Spectrum Disorders

Benjamin I. Goldstein, M.D., Ph.D.[a], **Francis Lotrich, M.D., Ph.D.**[b], **David Axelson, M.D.**[c], **Mary Kay Gill, R.N., M.S.N.**[b], **Heather Hower, M.S.W.**[d], **Tina R. Goldstein, Ph.D.**[b], **Jieyu Fan, Ph.D.**[b], **Shirley Yen, Ph.D.**[d], **Rasim Diler, M.D.**[b], **Daniel Dickstein, M.D.**[d], **Michael Strober, Ph.D.**[e], **Satish Iyengar, Ph.D.**[f], **Neal D. Ryan, M.D.**[b], **Martin B. Keller, M.D.**[d], and **Boris Birmaher, M.D.**[b]

[a]Department of Psychiatry, Sunnybrook Health Sciences Centre, University of Toronto Faculty of Medicine, 2075 Bayview Ave., FG-53, Toronto, ON, M4N-3M5, Canada

[b]Western Psychiatric Institute and Clinic, University of Pittsburgh School of Medicine, 3811 O'Hara St., Pittsburgh, PA, 15213, USA

[c]Department of Psychiatry, Nationwide Children's Hospital and The Ohio State College of Medicine, 1670 Upham Dr., Columbus, OH, 43210

[d]Department of Psychiatry and Human Behavior, Alpert Medical School of Brown University, Box G-BH, Providence, RI, 02912, USA

[e]Department of Psychiatry and Biobehavioral Sciences, David Geffen School of Medicine, University of California at Los Angeles, 760 Westwood Plaza, Mail Code 175919, Los Angeles, CA, 90095, USA

[f]Department of Statistics, University of Pittsburgh, 2717 Cathedral of Learning, Pittsburgh, PA, 15260, USA

Abstract

Objectives—Despite burgeoning literature in middle-aged adults, little is known regarding pro-inflammatory markers (PIMs) among adolescents and young adults with bipolar disorder. Similarly, few prior studies have considered potential confounds when examining the association between PIMs and bipolar disorder characteristics. We therefore examined these topics in the Course and Outcome of Bipolar Youth (COBY) study.

Methods—Subjects were 123 adolescents and young adults (20.4±3.8 years; range 13.4–28.3 years) in COBY, enrolled between October 2000 and July 2006. DSM-IV diagnoses were determined using the Schedule for Affective Disorders and Schizophrenia for school-aged children

Corresponding author: B Goldstein, Department of Psychiatry, Sunnybrook Health Sciences Centre; 2075 Bayview Ave., FG53, Toronto, Ontario, M4N-3M5; Telephone: 416-480-5328; Fax: 416-480-6818; ; Email: benjamin.goldstein@sunnybrook.ca

FINANCIAL DISCLOSURES

Disclosure: Gill, Hower, and Sorioso report no biomedical financial interests or potential conflicts of interest.

Findings were presented in part at the Annual Meeting of the Society of Biological Psychiatry, San Francisco, May 2013, the 10th International Conference on Bipolar Disorders, Miami, June 2013, and the 60th Annual Meeting of the American Academy of Child & Adolescent Psychiatry, Orlando, October, 2013.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

(KSADS). Clinical characteristics over the preceding 6 months, including mood, comorbidity and treatment, were evaluated using the Longitudinal Interval Follow-up Evaluation (LIFE). Serum levels of interleukin (IL)-6, tumor necrosis factor (TNF)-α, and high-sensitivity C-reactive protein (hsCRP) were assayed. Primary analyses examined the association of PIMs with bipolar disorder characteristics over the preceding 6 months.

Results—Several lifetime clinical characteristics were significantly associated with PIMs in multivariable analyses, including longer illness duration (p=0.005 for IL-6; p=0.0004 for hsCRP), suicide attempts (p=0.01 for TNF-α), family history of suicide attempts or completion (p=0.01 for hsCRP), self-injurious behavior (p=0.005 for TNF-α), SUD (p<0.0001 for hsCRP) and family history of SUD (p=0.02 for TNF-α; p=0.01 for IL-6). The following bipolar disorder characteristics over the preceding 6 months remained significantly associated with PIMs in multivariable analyses that controlled for differences in comorbidity and treatment. For TNF-α: percentage of weeks with psychosis (χ^2=5.7, p=0.02). For IL-6: percentage of weeks with subthreshold mood symptoms (χ^2=8.3, p=0.004), and any suicide attempt (χ^2=6.1, p=0.01). For hsCRP: maximum severity of depressive symptoms (χ^2=8.3, p=0.004).

Conclusions—PIMs may be relevant to bipolar disorder characteristics as well as other clinical characteristics among adolescents and young adults with bipolar disorder. Traction toward validating PIMs as clinically relevant biomarkers in bipolar disorder will require repeated measures of PIMs and incorporation of relevant covariates.

Keywords

bipolar disorder; adolescent; young adult; inflammation; C-reactive protein; interleukin-6; tumor necrosis factor-alpha

INTRODUCTION

Pro-inflammatory markers (PIMs) such as interleukin (IL)-6, tumor-necrosis factor (TNF)-α, and c-reactive protein (CRP) PIMs could potentially serve as biomarkers for psychiatric diagnosis, disease course, and therapeutic intervention.[1–3] PIMs are also leading candidate biomarkers in bipolar disorder specifically.[4,5] PIMs are implicated in other medical illnesses such as rheumatoid arthritis and cardiovascular disease (CVD), in which they are used to evaluate and predict illness activity and treatment response.[6] Bipolar disorder may in some respects be a multi-systemic inflammatory illness, explaining in part the high rate of medical comorbidity.[1,7]

Three recent meta-analyses confirm elevated PIMs during acute episodes of mania and/or depression among bipolar disorder adults.[8–10] Limitations highlighted in these meta-analyses include small sample sizes and lack of covariate inclusion in most studies. Broader interrogation of putative confounds of the association between PIMs and mood symptoms in bipolar disorder is warranted if PIMs are to gain traction as biomarkers of illness activity in bipolar disorder, as they are for other inflammatory conditions.

Unlike the robust literature regarding neuro-cognitive and neuro-imaging biomarkers among youth and adults with bipolar disorder, the peripheral biomarker literature in bipolar disorder has been largely constrained to adults.[4] Signal detection may be enhanced among

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

adolescents and young adults with bipolar disorder, due to shorter illness duration and less medical comorbidity versus middle-aged adults with bipolar disorder.[11] In our pilot study of PIMs among 30 adolescents in the Course and Outcome of Bipolar Youth (COBY) study, the only one to date regarding PIMs among bipolar disorder adolescents, levels of high-sensitivity CRP (hsCRP) were significantly associated with hypo/manic symptoms and 40% of the sample had hsCRP levels considered high-risk for CVD among adults.[12] That study was constrained by modest sample size, precluding an examination of confounds. Moreover, blood samples in that study were collected at various times of day, some in fasting status and others not. These limitations constrained power and sensitivity respectively.

We therefore examined this topic in a large sample of adolescents and young adults in COBY, adding PIMs to study procedures in 2009. Because of limited prior research in this age-group, we planned for an interim analysis of the initial time point after obtaining the first blood samples. However, data for 123 participants was available when the cytokine assays were performed, and is therefore included. Although repeated measures of PIMs are planned, the current study assesses PIMs at a single time-point. The selected PIMs are not specific to bipolar disorder, and are not intended to serve as diagnostic biomarkers. Rather, our goal is to help move the field closer to clinically relevant biomarkers of illness activity in early-onset bipolar disorder. This invokes the need for within-group (i.e. only bipolar disorder participants) analyses, an approach that has been adopted in other recurrent diseases. We hypothesized that PIMs would be significantly associated with the severity and burden of hypo/manic and depressive symptoms in the preceding 6 month epoch, independent of potentially confounding variables.

METHOD

Participants

The methods for COBY have been described in detail elsewhere.[13,14] Briefly, the study included youths ages 7 to 17 years 11 months at intake, with Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) bipolar disorder-I or -II or operationally defined bipolar disorder not otherwise specified (NOS). Participants in the current analysis included 123 adolescents and young adults, mean age 20.4±3.8 years, enrolled in COBY[13,15] with bipolar disorder-I (58.5%), -II (6.5%), or -NOS (35%). Twenty of these participants had also participated in our prior pilot study, but provided a subsequent blood sample for the current study. Consecutive COBY subjects contacted for follow-up assessments at the Pittsburgh and Brown sites were invited to participate. Exclusion criteria were: infectious illness within 14 days, known inflammatory or auto-immune illness, use of steroidal medication or insulin within one month, and self-reported alcohol or illicit drug use within 24-hours (two subjects who reported regular cigarette smoking were included). Twenty-one participants declined this COBY procedure, primarily due to needle phobia (n=6) and travel distance (n=10). Descriptive findings are listed in Table 1.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Procedures

Each participating university's institutional review board approved the study. At intake, participants and parents provided informed consent and were directly interviewed for the presence of current and lifetime psychiatric disorders in the adolescents.

Psychiatric and Anthropometric Measures

Psychiatric diagnoses were ascertained with the Schedule for Affective Disorders and Schizophrenia for School-Age Children—Present and Lifetime Version (K-SADS-PL)[16], the Kiddie Mania Rating Scale (K-MRS)[17], and the depression section of the K-SADS-P.[18] Psychiatric symptoms over the preceding 6-month epoch were assessed using the Longitudinal Interval Follow-Up Evaluation (LIFE)[19] and tracked on a week-by-week basis using this instrument's Psychiatric Status Rating (PSR) scales. Analyses focused on PSR scores over the 6 months preceding the blood draw for PIMs, as this is the standard interval between COBY visits.

All assessments were conducted by research staff trained to reliably administer the interviews; interview results were presented to child psychiatrists or psychologists, who confirmed the diagnoses and the PSR scores. As previously reported, reliability of the KSADS and PSR in COBY is good-very good.[15,20]

Those variables that were ascertained during the preceding 6-month epoch as well as at intake are listed in Table 2. Family psychiatric history was ascertained using the Family History Screen.[21] Socioeconomic status was ascertained at intake using the four-factor Hollingshead scale.[22] Abuse was ascertained using the KSADS-PL. Lifetime and current pharmacological treatment exposure were obtained at the intake assessment. In addition, the Psychotropic Treatment Record and the Psychosocial Treatment Schedule of the LIFE were used to ascertain treatment exposure in the preceding 6-month epoch on a week-by-week basis. Weekly exposure was dichotomized (yes/no) for each of three classes: antimanic, antidepressant, and stimulant. Weekly exposure to psychosocial treatments was similarly examined for three categories of intensity: inpatient hospitalization/residential treatment, specialized intensive services, and standard outpatient services. Global functioning was assessed at intake using the Children's Global Assessment Scale (C-GAS).[23]

Weight and height was measured using a Tanita scale and SECA electronic stadiometer. Obesity was defined as age- and sex-adjusted body mass index (BMI) $\geq 95^{th}$ percentile according to Center for Disease Control BMI norms. Systolic and diastolic blood pressure was measured twice using Life Source automated blood pressure monitors, with analyses examining the mean measurements.

Biochemical Assays

Blood (20ml) was drawn from each subject between 9:00am–12:00pm after a 10-hour fast, immediately centrifuged at 3000g for 5 minutes, and stored at −80°C until assayed at the University of Pittsburgh. Serum IL-6 levels were determined using a high sensitivity quantitative sandwich enzyme linked immune sorbent (ELISA) assay kit according to the manufacturer's instructions (Alpco). Serum levels of hsCRP and TNF-α were also

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

determined using ELISA in a similar fashion to IL-6. Measurement of glucose and lipids was completed at the local hospital laboratory. Detection limits were 0.09 pg/ml for TNF-α, 0.1pg/ml for IL-6, and 0.00092 ug/ml for hsCRP. Intra-assay coefficient of variability was 5.3–6.7 for TNF-α, 4.7–8.3 for IL-6, and 5.5–6.0 for hsCRP. Inter-assay coefficient of variability was 7.7–9.7 for TNF-α, 6.7–10.0 for IL-6, and 11.6–13.8 for hsCRP.

Statistical Analyses

Statistical analysis were performed using SAS (9.3) software. Correlations among the PIMs was examined with Pearson correlation coefficients. Based on the observed distributions of PIMs, generalized linear models with Gamma distribution were applied in the following analysis. Type III test results are reported. Effect sizes (Cohen's f^2) were computed using the following equation: Effect size = [Deviance (Reduced) – Deviance (Full)]/Deviance (Full), where the full model is the gamma regression model including the explanatory variable of interest and the reduced model is the gamma regression model excluding the explanatory variable of interest. For f^2, 0.02 is considered a small effect size, 0.15 is a medium effect size, and 0.35 is a large effect size.[24]

The variables with $p<0.2$ in univariate analyses were included into the multivariable model through stepwise procedure. Analyses regarding mood symptoms were undertaken *a priori* and were not adjusted for multiple comparisons. For other univariate analyses, correction via false discovery rate (FDR) was undertaken. We recognize that the current inclusive multivariable approach may lead to over-fitted models, and that we could have opted to rely on heuristics to select covariates. However, given the limited data available to inform the *a priori* selection of covariates, we opted to be as atheoretical as possible and allow the data to inform our variable selection.

RESULTS

Association of PIMs with lifetime characteristics

Table 1 presents participant characteristics associated with PIMs. Mean±standard deviation (SD) levels were 2.73±0.75 pg/ml for TNF-α, 0.77±0.78 pg/ml for IL-6, and 2.60±4.36 μg/ml for hsCRP. IL-6 was significantly correlated with TNF-α ($r=0.19$, $p=0.04$), and with IL-6 ($r=0.38$, $p<0.0001$). hsCRP was not significantly correlated with TNF-α ($r=0.10$, $p=0.29$). There were no significant associations between age, sex, race, SES, or bipolar disorder subtype with any of the PIMs. Longer duration of bipolar disorder was significantly associated with higher IL-6 and hsCRP. Earlier age of bipolar disorder onset was also associated with higher hsCRP. Among lifetime comorbidities, the only significant association was between substance dependence and lower hsCRP. Family history of Attention Deficit Hyperactivity Disorder (ADHD) and family history of substance abuse were each associated with significantly lower IL-6 and hsCRP. Among these variables, only the association of higher hsCRP with earlier age of bipolar disorder onset remained significant after FDR correction (corrected $p=0.04$).

Multivariable analyses examined all variables that were associated with PIMs at $p<0.2$ (before FDR correction). The following variables remained significantly associated with

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

PIMs in multivariable analyses. For TNF-α: SES (χ^2=7.2, p=0.007), white race (χ^2=3.8, p=0.05), lifetime suicide attempt (χ^2=6.3, p=0.01), lifetime self-injurious behavior (χ^2=8.0, p=0.005), and family history of SUD (χ^2=5.4, p=0.02). For IL-6: age (χ^2=3.9, p=0.05), duration of bipolar disorder (χ^2=7.8, p=0.005), and family history of SUD (χ^2=6.1, p=0.01). For hsCRP: age (χ^2=22.4, p<0.0001), SES (χ^2=9.2, p=0.002), duration of bipolar disorder (χ^2=12.8, p=0.0004), lifetime comorbid SUD (χ^2=18.2, p<0.0001), and family history of suicide attempt or completion (χ^2=6.4, p=0.01).

Association of PIMS with clinical characteristics during the preceding 6 month epoch

Table 2 presents the associations between PIMs and the prospectively ascertained symptom burden and severity across mood states, as well as psychosis and comorbidities, over the 6 month epoch preceding the blood draw. Greater percentage of weeks in euthymia was significantly associated with lower IL-6, whereas greater percentage of weeks with subthreshold mood symptoms was significantly associated with higher IL-6. Similarly, greater percentage of weeks with full-threshold major depression was significantly associated with higher hsCRP. Maximum depressive severity in the preceding 6 month epoch was significantly associated with higher IL-6 and higher hsCRP, and there was a trend toward an association between maximum hypo/manic severity and higher IL-6 (p=0.05). Greater percentage of weeks with psychosis in the preceding 6 month epoch was significantly associated with higher TNF-α, and greater percentage of weeks with suicidal ideation was significantly associated with higher IL-6. There were no significant associations between the percentage of weeks with comorbidities and any of the PIMs. IL-6 was the only PIM that was significantly associated with treatment. Specifically, exposure to any psychotropic medication, antidepressants, stimulants, any psychosocial treatment, and outpatient services were each significantly associated with higher IL-6. None of the mood findings remained significant after FDR correction. Among non-mood findings for IL-6, the following variables remained significant after FDR correction: antidepressant medication, stimulants, outpatient treatment, and suicidal ideation. None of the non-mood findings for TNF-α or hsCRP survived FDR correction.

Multivariable analyses examined all variables that were associated with PIMs at p<0.2, yielding several significant associations with PIMs. For TNF-α: percentage of weeks with psychosis (χ^2=5.7, p=0.02). For IL-6: percentage of weeks with subthreshold mood symptoms (χ^2=8.3, p=0.004), percentage of weeks with antidepressant medication (χ^2=9.1, p=0.003), and any suicide attempt (χ^2=6.1, p=0.01). For hsCRP: age (χ^2=7.0, p=0.008), obesity (χ^2=4.6, p=0.03), percentage of weeks with SUD (χ^2=11.5, p=0.007), and maximum severity of depressive symptoms (χ^2=8.3, p=0.004).

We conducted exploratory analyses examining the associations between PIMs and mood symptoms during the week prior to the blood draw and did not identify any significant associations.

Association of PIMs with metabolic syndrome variables

Table 3 presents the associations between PIMs and concurrently measured components of the metabolic syndrome (obesity, hypertension, dysglycemia, dyslipidemia). Obesity was

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

significantly associated with higher IL-6 and higher hsCRP. Higher (i.e. better) levels of HDL were significantly associated with lower IL-6, with a trend toward lower hsCRP (p=0.09). Higher (i.e. worse) levels of triglycerides were significantly associated with higher TNF-α. No significant associations with glucose, systolic blood pressure, or diastolic blood pressure were observed.

DISCUSSION

This is the largest study to date to examine PIMs among adolescents and young adults with bipolar disorder, and the largest study to date to examine multiple PIMs across multiple mood states in bipolar disorder in any age group. Previous large studies in middle age bipolar disorder adults have either included only euthymic subjects (N=121)[25] or examined a single PIM.[26–28] Despite their young age, levels of PIMs were detectable for all subjects. Indeed, mean levels of hsCRP are above the threshold considered to confer increased risk for CVD among adults.[6] Present findings support in part the primary hypothesis that PIMs are associated with mood symptom severity and burden in this population. Some distinctions between the different PIMs were observed, namely that hsCRP and IL-6 were associated with mood outcomes but not psychosis, and TNF-α was associated with psychotic symptom burden but not mood. PIMs were also associated with bipolar disorder duration, comorbidity, treatment, metabolic dysregulation, and family psychiatric history. The relatively large sample size allowed adequate power to detect significant associations between PIMs and putative confounds that may explain in part the previously described associations between PIMs and mood symptoms in bipolar disorder. Complexity and heterogeneity are inherent aspects of bipolar disorder internationally.[29] Present findings underscore the importance of incorporating the complexity and heterogeneity of bipolar disorder in the process of biomarker discovery and validation.

This study has three primary limitations. First, this study is based on a single measurement of PIMs, which precludes conclusions regarding causality and/or the direction of the observed associations. Ultimately, repeated-measures analyses will be informative in predicting treatment response and illness activity prospectively. Indeed, COBY is ascertaining repeated measures of PIMs and future reports will examine PIMs prospectively. Second, we selected three leading PIMs that were supported by the literature at the time this study was conceived. A broader approach could have identified other novel PIMs; however, we opted for a conservatively selective approach informed by the existing literature. Third, despite the fact that this is among the largest studies in the world literature on this topic, biomarker validation in psychiatry will require much larger samples. In addition, this study did not include a healthy and/or clinical control group; as such, it is not clear whether or not the associations observed in the current study are specific to bipolar disorder.

In support of our primary hypothesis, PIMs were associated with several measures of mood severity and burden over the preceding 6 month epoch. IL-6 levels were negatively associated with percentage of weeks euthymic, and in turn positively associated with percentage of weeks with subthreshold mood symptoms. IL-6 levels were also positively associated with maximum depressive and maximum hypo/manic severity. hsCRP levels were positively associated with percentage of weeks with full-threshold major depression and

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

with maximum depressive severity. Only the association between hsCRP and maximum severity of depressive symptoms remained significant in multivariable models. Numerous studies among adults have also reported cross-sectional associations between mood symptoms and PIMs.[8–10,30] The direction of the current cross-sectional findings is uncertain, and no prior studies in bipolar disorder address directionality. Previous evidence from non-bipolar disorder samples suggests bidirectionality.[31–34]

Younger age of bipolar disorder onset was associated with higher hsCRP in univariate analyses. In multivariable analyses, duration of bipolar disorder was positively associated with levels of IL-6 and hsCRP. Among prior studies of adults with bipolar disorder that have examined this topic, one study found that PIMs are positively associated with duration of bipolar disorder[35], whereas others have not found significant associations with bipolar disorder duration and/or age of onset.[36–39] One study found that IL-6 levels are higher in early-stage bipolar disorder (<3 years duration) whereas TNF-α levels are higher in late-stage bipolar disorder (>10 years duration).[40] Although PIMs have been invoked in theoretical models of bipolar disorder neuroprogression, additional studies are needed in order to clarify whether these markers are associated with or predict different illness stages.[5]

Treatment-related findings were only observed for IL-6, which was associated with antidepressant and stimulant treatment and with overall outpatient psychosocial treatment. Given the naturalistic design and the interview-based assessment of treatment exposure (vs. medication levels or reviewing health records), together with the robust contradictory evidence from clinical and preclinical studies that antidepressants and mood-stabilizing medications in fact decrease levels of PIMs[1], these findings should be interpreted as tentative. Of 10 prior studies among adults with bipolar disorder that have reported on the association between medication status and PIMs, 6 found no significant association and 4 found non-replicated associations.[8] Clearly, medications and psychosocial treatments are important to consider when examining PIMs in bipolar disorder. However, naturalistic studies are likely to be affected by selection bias (e.g. more treatments for more symptomatic patients, non-adherence, etc.) As such, analyses regarding mechanistic associations between treatment and PIMs in bipolar disorder are likely best reserved for preclinical studies and controlled trials.

There were several significant associations between PIMS and personal and family history of suicidality. These findings converge with preliminary prior evidence that inflammation is associated with suicidality among adults with MDD.[41] Similarly, PIMs were significantly associated with personal and family history of SUD. Some prior studies have found that substance use is associated with increased inflammation, whereas other studies have found the opposite.[42–44] This relationship appears to depend in part on type, pattern, and timing of substance use in relation to the assessment of inflammation.[45] Finally, present findings did not confirm prior reports that the link between mood and PIMs may be stronger among those with history of early adversity/abuse compared to those without such a history.[46] Reasons for the lack of findings regarding abuse history are uncertain, but may relate to differences between MDD and bipolar disorder, the young age of the current sample, or other unknown factors. Finally, present findings support an association between PIMs and metabolic syndrome components. These findings converge with abundant evidence that metabolic

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

syndrome components are associated with inflammation, including among adults with depression symptoms.[47–49]

In summary, this is the largest study to date that examines multiple PIMs in relation to mood symptoms and other characteristics of bipolar disorder in adolescents and young adults. This study confirms important associations between PIMs and illness activity in bipolar disorder, and identifies several potentially important covariates that should be considered in future studies on this topic. Given that increased PIMs are found in numerous psychiatric and medical conditions, PIMs are unlikely to serve as diagnostic biomarkers that can distinguish bipolar disorder from other related conditions. Ultimately, the value of PIMs as biomarkers for this population will therefore rely on their capacity to address other clinical issues such as prediction of illness course, and treatment selection and evaluation. Traction toward validating PIMs as clinically relevant biomarkers in bipolar disorder will require repeated measures of PIMs and incorporation of other relevant clinical characteristics. This approach will optimize signal to noise ratio by allowing for within-subject comparisons. Future studies employing this approach within the COBY sample are underway.

Acknowledgments

This research was supported by the National Institute of Mental Health Grants MH059929 (to Dr. Birmaher), MH59691 (to Drs. Keller/Yen), and MH59977 (to Dr. Strober). Dr. Goldstein is supported by a CIHR New Investigator Award. Dr. Iyengar and Fan are the study statistical experts. The authors thank Denise Sorioso, B.S., University of Pittsburgh, for her assistance with the biological assays.

Dr. B. Goldstein has received honoraria from Purdue Pharma. Dr. T. Goldstein receives royalties from Guilford Press and grant support from NIMH, NIDA, and the Pittsburgh Foundation. Dr. Strober receives support from the Resnick Endowed Chair in Eating Disorders. Dr. Keller receives research support from Pfizer, and has received honoraria from Medtronic. Dr. Birmaher is a consultant for Schering-Plough, participated in a forum sponsored by Forest, has or will receive royalties for publications from Random House, Inc, and Lippincott Williams and Wilkins, and has received grant support from NIMH. Drs. Lotrich, Axelson, Ryan, Yen, Iyengar, Diler, Fan, and Dickstein, and Mss.

References

1. Goldstein BI, Kemp DE, Soczynska JK, McIntyre RS. Inflammation and the phenomenology, pathophysiology, comorbidity, and treatment of bipolar disorder: a systematic review of the literature. Journal of Clinical Psychiatry. 2009; 70(8):1078–1090. [PubMed: 19497250]
2. Miller AH, Maletic V, Raison CL. Inflammation and its discontents: the role of cytokines in the pathophysiology of major depression. Biological Psychiatry. 2009; 65(9):732–741. [PubMed: 19150053]
3. Mitchell RHB, Goldstein BI. Inflammation in children and adolescents with neuropsychiatric disorders: a systematic review. Journal of the American Academy of Child & Adolescent Psychiatry. 2014; 53(3):274–296. [PubMed: 24565356]
4. Frey BN, Andreazza AC, Houenou J, et al. Biomarkers in bipolar disorder: A positional paper from the International Society for Bipolar Disorders Biomarkers Task Force. Australian and New Zealand Journal of Psychiatry. 2013; 47(4):321–332. [PubMed: 23411094]
5. Berk M, Kapczinski F, Andreazza AC, et al. Pathways underlying neuroprogression in bipolar disorder: Focus on inflammation, oxidative stress and neurotrophic factors. Neuroscience & Biobehavioral Reviews. 2011; 35(3):804–817. [PubMed: 20934453]
6. Ridker PM, Cushman M, Stampfer MJ, Tracy RP, Hennekens CH. Inflammation, Aspirin, and the Risk of Cardiovascular Disease in Apparently Healthy Men. N Engl J Med. 1997; 336(14):973–979. [PubMed: 9077376]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

7. Kupfer DJ. The Increasing Medical Burden in Bipolar Disorder. JAMA. 2005; 293(20):2528–2530. [PubMed: 15914754]
8. Munkholm K, Braüner JV, Kessing LV, Vinberg M. Cytokines in bipolar disorder vs. healthy control subjects: A systematic review and meta-analysis. Journal of Psychiatric Research. 2013; 47(9): 1119–1133. [PubMed: 23768870]
9. Munkholm K, Vinberg M, Vedel Kessing L. Cytokines in bipolar disorder: A systematic review and meta-analysis. Journal of Affective Disorders. 2013; 144:16–27. [PubMed: 22749156]
10. Modabbernia A, Taslimi S, Brietzke E, Ashrafi M. Cytokine Alterations in Bipolar Disorder: A Meta-Analysis of 30 Studies. Biological Psychiatry. 2013; 74(1):15–25. [PubMed: 23419545]
11. Goldstein B, Young LT. Toward Clinically Applicable Biomarkers in Bipolar Disorder: Focus on BDNF, Inflammatory Markers, and Endothelial Function. Current Psychiatry Reports. 2013; 15(12):1–7.
12. Goldstein BI, Collinger KA, Lotrich F, et al. Preliminary findings regarding pro-inflammatory markers and brain-derived neurotrophic factor among adolescents with bipolar spectrum disorders. Journal of Child & Adolescent Psychopharmacology. 2011; 21(5):479–484. [PubMed: 22040193]
13. Axelson D, Birmaher B, Strober M, et al. Phenomenology of children and adolescents with bipolar spectrum disorders. Archives of General Psychiatry. 2006; 63(10):1139–1148. [PubMed: 17015816]
14. Birmaher B, Axelson D, Strober M, et al. Clinical course of children and adolescents with bipolar spectrum disorders. Archives of General Psychiatry. 2006; 63(2):175–183. [PubMed: 16461861]
15. Birmaher B, Axelson D, Goldstein B, et al. Four-Year Longitudinal Course of Children and Adolescents With Bipolar Spectrum Disorders: The Course and Outcome of Bipolar Youth (COBY) Study. Am J Psychiatry. 2009; 166(7):795–804. [PubMed: 19448190]
16. Kaufman J, Birmaher B, Brent D, et al. Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL): Initial Reliability and Validity Data. Journal of the American Academy of Child & Adolescent Psychiatry. 1997; 36(7):980–988. [PubMed: 9204677]
17. Axelson D, Birmaher BJ, Brent D, et al. A preliminary study of the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children mania rating scale for children and adolescents. Journal of Child & Adolescent Psychopharmacology. 2003; 13(4):463–470. [PubMed: 14977459]
18. Chambers WJ, Puig-Antich J, Hirsch M, et al. The assessment of affective disorders in children and adolescents by semistructured interview. Test-retest reliability of the schedule for affective disorders and schizophrenia for school-age children, present episode version. Archives of General Psychiatry. 1985; 42(7):696–702. [PubMed: 4015311]
19. Keller MB, Lavori PW, Friedman B, et al. The Longitudinal Interval Follow-up Evaluation. A comprehensive method for assessing outcome in prospective longitudinal studies. Archives of General Psychiatry. 1987; 44(6):540–548. [PubMed: 3579500]
20. Axelson DA, Birmaher B, Strober MA, et al. Course of Subthreshold Bipolar Disorder in Youth: Diagnostic Progression From Bipolar Disorder Not Otherwise Specified. Journal of the American Academy of Child & Adolescent Psychiatry. 2011; 50(10):1001–1016. [PubMed: 21961775]
21. Weissman MM, Wickramaratne P, Adams P, Wolk S, Verdeli H, Olfson M. Brief screening for family psychiatric history: the family history screen. Arch Gen Psychiatry. 2000; 57(7):675–682. [PubMed: 10891038]
22. Hollingshead, A. Four-factor Index of Social Status. New Haven: Yale University; 1975.
23. Shaffer D, Gould MS, Brasic J, et al. A children's global assessment scale (CGAS). Archives of General Psychiatry. 1983; 40(11):1228–1231. [PubMed: 6639293]
24. Cohen, J. Statistical power analysis for the behavioral sciences. 2nd. Hillsdale, NJ: Lawrence Earlbaum Associates; 1988.
25. Remlinger-Molenda A, Wojciak P, Michalak M, Karczewski J, Rybakowski JK. Selected cytokine profiles during remission in bipolar patients. Neuropsychobiology. 2012; 66(3):193–198. [PubMed: 22948566]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

26. Dickerson F, Stallings C, Origoni A, Boronow J, Yolken R. C-reactive protein is associated with the severity of cognitive impairment but not of psychiatric symptoms in individuals with schizophrenia. Schizophrenia Research. 2007; 93(1–3):261–265. [PubMed: 17490859]
27. Hope S, Dieset I, Agartz I, et al. Affective symptoms are associated with markers of inflammation and immune activation in bipolar disorders but not in schizophrenia. Journal of Psychiatric Research. 2011; 45(12):1608–1616. [PubMed: 21889167]
28. Breunis MN, Kupka RW, Nolen WA, et al. High numbers of circulating activated T cells and raised levels of serum IL-2 receptor in bipolar disorder. Biological Psychiatry. 2003; 53(2):157–165. [PubMed: 12547472]
29. Merikangas KR, Jin R, He J-P, et al. Prevalence and Correlates of Bipolar Spectrum Disorder in the World Mental Health Survey Initiative. Arch Gen Psychiatry. 2011; 68(3):241–251. [PubMed: 21383262]
30. Dowlati Y, Herrmann N, Swardfager W, et al. A meta-analysis of cytokines in major depression. Biological Psychiatry. 2010; 67(5):446–457. [PubMed: 20015486]
31. Copeland WE, Shanahan L, Worthman C, Angold A, Costello EJ. Cumulative depression episodes predict later C-reactive protein levels: a prospective analysis. Biological Psychiatry. 2012; 71(1): 15–21. [PubMed: 22047718]
32. Lotrich FE, Ferrell RE, Rabinovitz M, Pollock BG. Risk for depression during interferon-alpha treatment is affected by the serotonin transporter polymorphism. Biological Psychiatry. 2009; 65(4):344–348. [PubMed: 18801474]
33. Pasco JA, Nicholson GC, Williams LJ, et al. Association of high-sensitivity C-reactive protein with de novo major depression. British Journal of Psychiatry. 2010; 197:372–377. [PubMed: 21037214]
34. Matthews KA, Schott LL, Bromberger JT, Cyranowski JM, Everson-Rose SA, Sowers M. Are there bi-directional associations between depressive symptoms and C-reactive protein in mid-life women? Brain, Behavior, & Immunity. 2010; 24(1):96–101.
35. Barbosa IG, Huguet RB, Mendonca VA, et al. Increased plasma levels of soluble TNF receptor I in patients with bipolar disorder. European Archives of Psychiatry & Clinical Neuroscience. 2011; 261(2):139–143. [PubMed: 20446090]
36. Tsai SY, Yang YY, Kuo CJ, Chen CC, Leu SJ. Effects of symptomatic severity on elevation of plasma soluble interleukin-2 receptor in bipolar mania. Journal of Affective Disorders. 2001; 64(2–3):185–193. [PubMed: 11313085]
37. Cetin T, Guloksuz S, Cetin EA, et al. Plasma concentrations of soluble cytokine receptors in euthymic bipolar patients with and without subsyndromal symptoms. BMC Psychiatry. 2012; 12:158. [PubMed: 23013558]
38. Kim YK, Suh IB, Kim H, et al. The plasma levels of interleukin-12 in schizophrenia, major depression, and bipolar mania: effects of psychotropic drugs. Molecular Psychiatry. 2002; 7(10): 1107–1114. [PubMed: 12476326]
39. Kim Y-K, Myint A-M, Lee B-H, et al. T-helper types 1, 2, and 3 cytokine interactions in symptomatic manic patients. Psychiatry Research. 2004; 129(3):267–272. [PubMed: 15661320]
40. Kauer-Sant'Anna M, Kapczinski F, Andreazza AC, et al. Brain-derived neurotrophic factor and inflammatory markers in patients with early- vs. late-stage bipolar disorder. International Journal of Neuropsychopharmacology. 2009; 12(4):447–458. [PubMed: 18771602]
41. Janelidze S, Mattei D, Westrin A, Traskman-Bendz L, Brundin L. Cytokine levels in the blood may distinguish suicide attempters from depressed patients. Brain, Behavior, & Immunity. 2011; 25(2): 335–339.
42. Waldschmidt TJ, Cook RT, Kovacs EJ. Alcohol and inflammation and immune responses: summary of the 2006 Alcohol and Immunology Research Interest Group (AIRIG) meeting. Alcohol. 2008; 42(2):137–142. [PubMed: 18358993]
43. Halpern JH, Sholar MB, Glowacki J, Mello NK, Mendelson JH, Siegel AJ. Diminished interleukin-6 response to proinflammatory challenge in men and women after intravenous cocaine administration. Journal of Clinical Endocrinology & Metabolism. 2003; 88(3):1188–1193. [PubMed: 12629105]
44. Baker D, Jackson SJ, Pryce G. Cannabinoid control of neuroinflammation related to multiple sclerosis. British Journal of Pharmacology. 2007; 152(5):649–654. [PubMed: 17891167]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

45. Mandrekar P, Bala S, Catalano D, Kodys K, Szabo G. The opposite effects of acute and chronic alcohol on lipopolysaccharide-induced inflammation are linked to IRAK-M in human monocytes. Journal of Immunology. 2009; 183(2):1320–1327.

46. Danese A, Moffitt TE, Pariante CM, Ambler A, Poulton R, Caspi A. Elevated Inflammation Levels in Depressed Adults With a History of Childhood Maltreatment. Arch Gen Psychiatry. 2008; 65(4):409–415. [PubMed: 18391129]

47. Khaodhiar L, Ling PR, Blackburn GL, Bistrian BR. Serum levels of interleukin-6 and C-reactive protein correlate with body mass index across the broad range of obesity. Jpen: Journal of Parenteral & Enteral Nutrition. 2004; 28(6):410–415. [PubMed: 15568287]

48. Capuron L, Su S, Miller AH, et al. Depressive symptoms and metabolic syndrome: is inflammation the underlying link? Biological Psychiatry. 2008; 64(10):896–900. [PubMed: 18597739]

49. Miller GE, Freedland KE, Carney RM, Stetler CA, Banks WA. Pathways linking depression, adiposity, and inflammatory markers in healthy young adults. Brain, Behavior, & Immunity. 2003; 17(4):276–285.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

CLINICAL POINTS

- Numerous studies have linked inflammation with mood among middle-age adults with bipolar disorder. Few of these studies have accounted for comorbidity and/or treatment. Little is known about this topic among adolescents and young adults.
- Similar to adults, inflammation is associated with the symptomatic burden of bipolar disorder, and this association does not appear to be explained by treatment or comorbidity.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

J Clin Psychiatry. Author manuscript; available in PMC 2016 June 07.

Table 1

Association of pro-inflammatory markers with lifetime demographic, clinical, and familial characteristics

		TNF-α			IL-6			hsCRP		
	% or M (SD)	**χ^2**	**Effect Size**	**p-value**	**χ^2**	**Effect Size**	**p-value**	**χ^2**	**Effect Size**	**p-value**
Age	20.4 (3.8)	0.1	0.001	0.74	0.2	0.001	0.66	2.3	0.015	0.13
SES	2.8 (1.3)	2.2	0.020	0.14	0.8	0.006	0.36	3.4	0.023	0.07
Duration of BP	12.7 (3.1)	0	< 0.001	0.86	7	0.053	0.008	4.3	0.029	0.04
Race (% White)	79.7	2.7	0.020	0.1	0	< 0.001	0.88	0.2	0.001	0.64
Sex (% male)	61.8	1.6	0.010	0.21	1.7	0.012	0.2	0.5	0.004	0.47
BP subtype		0.1	0.001	0.71	1.3	0.010	0.25	0.7	0.004	0.41
Age of BP onset	8.6 (3.7)	0.5	0.004	0.48	2	0.021	0.09	10.8	0.075	0.001
ADHD	76.4	0.1	0.001	0.77	0	< 0.001	0.92	0.3	0.002	0.62
CD	27.6	0.2	0.002	0.66	0.3	0.002	0.57	1.5	0.010	0.23
ODD	61.8	0.3	0.002	0.62	0	< 0.001	0.93	3.6	0.024	0.06
Anxiety	80.5	0	< 0.001	0.87	3.7	0.028	0.05	0.4	0.002	0.54
Physical abuse	23.6	0.1	< 0.001	0.8	2.2	0.016	0.14	0	< 0.001	0.97
Sexual abuse	18.7	0.5	0.004	0.49	0.8	0.006	0.38	0	< 0.001	0.88
Psychiatric Hospitalization	65.9	2.4	0.020	0.12	0.1	< 0.001	0.73	2	0.013	0.16
Psychosis	36.6	2.3	0.020	0.13	0	< 0.001	0.83	1.1	0.007	0.3
Substance abuse	30.9	0	< 0.001	0.96	2.9	0.021	0.09	2.1	0.014	0.14
Substance dependence	17.9	1.5	0.012	0.23	1.4	0.011	0.23	7.4(−)^	0.050	0.007
SUD	33.3	0	< 0.001	0.88	3.9	0.029	0.05*	3.4	0.023	0.07
Suicide attempt	48	3.3	0.027	0.07	0	< 0.001	0.99	3.5	0.023	0.06
Self-injurious behavior	59.4	2.3	0.019	0.13	0.2	0.001	0.69	1.3	0.009	0.26
Suicidal ideation	78.9	0.2	0.002	0.66	2	0.015	0.16	0.1	< 0.001	0.83
Family psychiatric history (1st and 2nd degree)										

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

		TNF-α			IL-6			hsCRP		
	% or M (SD)	χ^2	Effect Size	p-value	χ^2	Effect Size	p-value	χ^2	Effect Size	p-value
Depression	89.4	1.2	0.010	0.27	0.8	0.006	0.39	0.1	< 0.001	0.8
Mania/hypomania	67.5	0	< 0.001	0.95	0	< 0.001	0.91	0	< 0.001	0.88
ADHD	55.3	0.3	0.002	0.6	5.6(−)	0.042	0.02	7.9(−)	0.053	0.01
CD	40.7	0	< 0.001	0.87	1.7	0.012	0.2	2	0.013	0.16
Schizophrenia	10.6	0.5	0.004	0.47	0	< 0.001	0.85	0.6	0.004	0.44
Anxiety	69.1	0.5	0.004	0.48	0.1	< 0.001	0.78	0.6	< 0.001	0.44
Substance abuse	61.8	0.5	0.004	0.48	7.6(−)	0.057	0.006	6.4(−)	0.043	0.01
Substance dependence	62.6	0.5	0.004	0.5	3.9	0.029	0.05	0.3	0.002	0.58
SUD	75.6	2.4	0.019	0.12	7.0(−)	0.052	0.008	1.5	0.010	0.22
Suicide attempt or completion	48.8	1.2	0.010	0.27	0.34	0.003	0.56	2.4	0.016	0.12

SES = Socio-economic Status; BP = Bipolar Disorder; ADHD = Attention Deficit Hyperactivity Disorder; CD = Conduct Disorder; ODD = Oppositional Defiant Disorder; SUD = Substance Use Disorder; ^ denotes negative association.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

J Clin Psychiatry. Author manuscript; available in PMC 2016 June 07.

Table 2

Association of pro-inflammatory markers with clinical characteristics during the preceding 6 month epoch

	n=123	TNF-α			IL-6			hsCRP		
		χ^2	Effect Size	p-value	χ^2	Effect Size	p-value	χ^2	Effect Size	p-value
% Weeks in Mood State During 6 Months Preceding Blood Draw (mean ± SD)										
No significant mood symptoms	56.9 (40.8)	0.1	< 0.001	0.78	10.8(−)^	0.083	0.001	1.9	0.013	0.17
Any sub-threshold mood state	28.5 (35.5)	0	< 0.001	0.84	6.7	0.050	0.010	0.4	0.003	0.53
Any full-threshold mood state	14.6 (28.9)	0	< 0.001	0.88	1.5	0.011	0.22	1.5	0.010	0.22
Full-threshold pure depression	8.6 (21.3)	0.2	0.002	0.66	2.9	0.021	0.09	4.5	0.031	0.03
Full-threshold pure mania/hypomania	3.3 (13.7)	0.3	0.003	0.56	0.2	0.001	0.68	0.6	0.004	0.43
Full-threshold Mix	0.4 (3.1)	0.6	0.005	0.45	0.1	< 0.001	0.75	0	< 0.001	0.89
Full-threshold Cycling	2.3 (10.9)	0.6	0.005	0.44	0.1	< 0.001	0.82	0	< 0.001	0.88
Suicidal ideation	1.8 (8.3)	0	< 0.001	0.86	7.8	0.059	0.005	3.6	0.024	0.06
Maximum Severity (PSR)										
Depression	3.1 (1.5)	0	< 0.001	0.86	6.4	0.048	0.012	9.6	0.066	0.002
Mania/Hypomania	2.4 (1.5)	0.1	0.001	0.72	3.8	0.028	0.05	0	< 0.001	0.97
% Weeks in Psychosis										
Psychosis	7.0 (25.2)	4.9	0.040	0.028	0.3	0.002	0.59	0.4	0.002	0.54
Comorbid Disorders (% weeks in past 6 months meeting full diagnostic criteria)										
Any Comorbid Disorder	74.5 (43.2)	1.6	0.013	0.21	0.4	0.003	0.51	0.2	0.001	0.68
SUD	32.6 (46.0)	0.1	< 0.001	0.74	1.8	0.013	0.18	3.5	0.023	0.06
ADHD	45.4 (49.9)	0.5	0.004	0.47	2.4	0.017	0.13	3.1	0.021	0.08
CD/ODD	28.4 (45.1)	0	< 0.001	0.87	1.7	0.012	0.2	0.7	0.005	0.41
Any Anxiety	40.8 (48.9)	0.5	0.004	0.49	0.1	< 0.001	0.72	0.4	0.003	0.52
% Weeks Receiving Medication over Preceding 6 Months (mean ± SD)										
Any Psychotropic Medication	52.0 (48.1)	0.4	0.003	0.53	6.6	0.049	0.011	1.4	0.009	0.24
Antimanic	38.2 (47.3)	0.6	0.005	0.44	0.7	0.005	0.404	0.6	0.004	0.45
Antidepressant	17.7 (35.9)	0.3	0.002	0.62	7.3	0.055	0.007	0.7	0.005	0.41

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

	n=123	TNF-α			IL-6			hsCRP		
		χ^2	Effect Size	p-value	χ^2	Effect Size	p-value	χ^2	Effect Size	p-value
Stimulants	22.6 (40.9)	0.1	< 0.001	0.78	6.2	0.046	0.013	0.3	0.002	0.59
% Weeks Receiving Treatment over Preceding 6 Months (mean ± SD)										
Any Psychosocial	22.1 (30.3)	0.7	0.005	0.41	5.3	0.039	0.022	0.3	0.002	0.61
Inpatient/Residential Treatment	3.2 (15.8)	0.2	0.001	0.67	1.1	0.008	0.297	0.5	0.003	0.47
Specialized Psychosocial Services	5.9 (23.4)	0	<0.001	0.92	0	<0.001	0.85	0.9	0.006	0.35
Outpatient Services	15.7 (20.2)	1.3	0.011	0.25	6.9	0.052	0.009	0.3	0.002	0.61

PSR = Psychiatric Status Rating; ADHD = Attention Deficit Hyperactivity Disorder; CD = Conduct Disorder; ODD = Oppositional Defiant Disorder; SUD = Substance Use Disorder;

^ denotes negative association.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Table 3

Association of pro-inflammatory markers with metabolic syndrome components

	n=123	TNF-α			IL-6			hsCRP		
		χ^2	Effect Size	p-value	χ^2	Effect Size	p-value	χ^2	Effect Size	p-value
BMI		0.1	< 0.001	0.97	10.3	0.077	0.006	15.9	0.108	<0.001
normal	44.6	0	< 0.001	0.86	0.8	0.006	0.38	2.6	0.018	0.11
overweight	23.1	0	< 0.001	0.96	5.9(−)^	0.044	0.015	8.0(−)	0.054	0.005
obese	32.2	0.1	< 0.001	0.81	8.1	0.060	0.004	13.4	0.091	<0.001
Glucose	91.9 (16.0)	2.1	0.017	0.15	2	0.015	0.16	0.5	0.003	0.49
Cholesterol	159.5 (29.2)	2.2	0.018	0.14	0.4	0.003	0.55	0.3	0.002	0.56
HDL Cholesterol	43.0 (11.9)	1.3	0.010	0.26	4.0(−)	0.029	0.05	3	0.020	0.09
LDL Cholesterol	98.0 (25.4)	2.2	0.018	0.14	0.9	0.006	0.35	1	0.007	0.31
Triglycerides	98.0 (81.4)	4	0.033	0.05*	1.8	0.014	0.18	0.8	0.005	0.38
Systolic blood pressure	116.1 (11.5)	0.5	0.004	0.50	0.1	0.001	0.71	1.3	0.009	0.25
Diastolic blood pressure	76.9 (10.1)	1.0	0.009	0.31	0	<0.001	0.96	0.2	0.001	0.70

BMI = Body Mass Index; HDL = High Density Lipoprotein; LDL = Low Density Lipoprotein;

^denotes negative association