

Low tumor necrosis factor- α levels predict symptom reduction during electroconvulsive therapy in major depressive disorder

Annamari Sorri^{1,2}  | Kaija Järventausta^{1,2} | Olli Kampman^{2,3} | Kai Lehtimäki⁴ |
Minna Björkqvist¹ | Kati Tuohimaa¹ | Mari Hämäläinen⁵ | Eeva Moilanen⁵ |
Esa Leinonen^{1,2}

¹Department of Psychiatry, Tampere University Hospital, Tampere, Finland

²Department of Psychiatry, School of Medicine, University of Tampere, Tampere, Finland

³Department of Psychiatry, Seinäjoki Hospital District, Seinäjoki, Finland

⁴Department of Neurosurgery, Neurology and Rehabilitation, Tampere University Hospital, Tampere, Finland

⁵The Immunopharmacology Research Group, Faculty of Medicine and Life Sciences, University of Tampere and Tampere University Hospital, Tampere, Finland

Correspondence

Annamari Sorri, Department of Psychiatry, Tampere University Hospital, Tampere, Finland.

Email: annamari.sorri@pshp.fi

Funding information

Competitive Research Funding of Tampere University Hospital, Grant/Award Number: 9U029

Abstract

Objective: Changes in the tumor necrosis factor- α (TNF α) have been associated with major depressive disorder (MDD). Findings concerning the effects of electroconvulsive therapy (ECT) on the TNF α level have been contradictory. The aim was to examine the immediate and long-term changes in the TNF α level and their associations with symptom reduction in patients with MDD during ECT.

Method: The study included 30 patients with MDD. Their TNF α levels were measured at baseline and 2 and 4 hr after the first, fifth and last ECT session. Depressive symptoms were assessed with the Montgomery-Asberg Depression Rating Scale (MADRS).

Results: The TNF α level decreased from baseline to the 2- and 4-hr measurements. There was a correlation between the first ECT session TNF α levels and the relative symptom reduction according to the MADRS score after the ECT series. Both the first (baseline) ECT and 4-hr TNF α levels were lower in responders than in nonresponders.

Conclusion: ECT consistently induced a decrease in the TNF α level after each studied session. A low TNF α level at the first ECT appeared to predict a symptom reduction. These findings suggest that TNF α might have a role in the pathogenesis in MDD and in the mechanism of action of ECT.

KEYWORDS

cytokine, electroconvulsive therapy, major depressive disorder, seizure

SIGNIFICANT OUTCOMES

These findings support the role of cytokines, especially TNF α , in depression.

ECT decreased TNF α levels during each ECT session.

Low TNF α levels during the first ECT session predict symptom reduction after the treatment.

LIMITATIONS

The number of patients is relatively small.

TNF α levels of normal controls were not available.

Plasma TNF α levels may be affected by anesthesia during ECT series.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2018 The Authors. *Brain and Behavior* published by Wiley Periodicals, Inc.

1 | INTRODUCTION

Electroconvulsive therapy (ECT) is considered to be the most efficacious treatment for severe major depressive disorder (MDD) (UK ECT Review Group, 2003). Thus, the main indications for ECT are severe psychotic MDD and treatment resistance in patients with MDD (American Psychiatric Association, 2001). However, the mechanism of action of ECT remains obscure.

Tumor necrosis factor- α (TNF α) is a proinflammatory cytokine that has been considered to be expressed in the brain only in response to pathological stimuli. However, TNF α as well as some other cytokines have recently been found to play an active role in neural plasticity and neurogenesis (Khairova, Machado-Vieira, Du, & Manji, 2009; Yirmiya & Goshen, 2011). The cytokine hypothesis of depression proposes that activation of the inflammatory system, which results in increased production of proinflammatory cytokines, contributes to the pathogenesis of MDD (Maes, 1995). In animal models, cytokine activation has produced depressive symptoms, a decreased hippocampal volume, and "sickness behavior" (Dunn, Swiergiel, & de Beaurepaire, 2005; Goshen et al., 2008; Lawson, McCusker, & Kelley, 2013). Immunotherapy with interleukin-2 or interferon- α is reportedly associated with cognitive impairment and a depressed mood as well as fatigue, sleep disturbances, irritability, and loss of appetite (Bonaccorso et al., 2001, 2002; Capuron, Ravaut, & Dantzer, 2001; Capuron et al., 2001; Dieperink, Willenbring, & Ho, 2000). Vaccines, which act as cytokine inducers, also cause a depressed mood in healthy individuals (Harrison et al., 2009).

Proinflammatory cytokines such as TNF α are associated with the actions of mood-relevant neurotransmitters, including the monoamines, by different pathways (Miller, Maletic, & Raison, 2009). However, the reported associations between TNF α and MDD or ECT are inconsistent due to different methodologies and variations in study populations. In addition, both plasma and serum TNF α levels have been reported. Several meta-analyses have revealed markedly higher concentrations of TNF α in depressed individuals than in healthy controls (Dowlati et al., 2010; Goldsmith, Rapaport, & Miller, 2016; Huang & Lee, 2007; Liu, Ho, & Mak, 2012). However, studies with no association with changes in the TNF α level and symptoms of MDD have been published (Haapakoski, Mathieu, Ebmeier, Alenius, & Kivimäki, 2015; Karlovic, Serretti, Vrkic, Martinac, & Marcinko, 2012; Yoon, Kim, Lee, Kwon, & Kim, 2012). This association has been questioned in a recent meta-analysis (Anisman, Ravindran, Griffiths, & Merali, 1999). It has also been hypothesized that the pathophysiological mechanisms of various subtypes of MDD might differ from one another with respect to dysregulation of the immune-inflammatory system (Lamers et al., 2013). One report suggested that atypical depression is associated with an elevated TNF α level (Janelidze, Mattei, Westrin, Träskman-Bendz, & Brundin, 2011). Elevated TNF α levels have also been associated with suicide attempts and dissociative symptoms (Abbasi, Hosseini, Modabbernia, Ashrafi, & Akhondzadeh, 2012; Bizik et al., 2014). The nonsteroidal anti-inflammatory drug celecoxib reportedly has a beneficial effect in patients with MDD as an adjuvant medication

(Akhondzadeh et al., 2009; Kargar et al., 2014; Müller et al., 2006). Additionally, celecoxib reduced the TNF α level after an ECT series in patients with bipolar disorder (Dantzer, O'Connor, Lawson, & Kelley, 2011).

It has been presumed that TNF α , through its induction of indoleamine 2,3-dioxygenase (IDO), activates the kynurenine pathway, which is considered to be associated with inflammation and depression. IDO catabolizes tryptophan into neuroactive kynurenine metabolites such as quinolic acid and 3-hydroxy kynurenine. These tryptophan metabolites are neurotoxic because they are able to generate oxidative radicals and act as N-methyl-N-aspartate receptor agonists (Haroon, Raison, & Miller, 2012; Maes, Mihaylova, Kubera, & Ringel, 2012; Schwarcz, Bruno, Muchowski, & Wu, 2012). Another metabolite of kynurenine, kynurenic acid, is considered to have neuroprotective properties (Haroon et al., 2012; Myint & Kim, 2003). It has been suggested that in patients with depression, activation of IDO could turn the kynurenine pathway toward the generation of neurotoxic metabolites (Guloksuz et al., 2015). ECT was recently reported to increase the levels of kynurenic acid, referring to the fact that ECT can alter the balance of the kynurenine pathway toward a neuroprotective course (Schwieler et al., 2016). Furthermore, ECT can reportedly decrease quinolic acid levels in patients with treatment-resistant depression (Hestad, Tønseth, Støen, Ueland, & Aukrust, 2003). Altogether, these findings imply that the mechanism of action of ECT is partly associated with the kynurenine pathway, which is induced by TNF α .

Some studies have addressed the association between TNF α and ECT (First, Spitzer, Gibbon, & Williams, 1996; Fluitman et al., 2011; Hestad et al., 2003; Rotter et al., 2013; Rush et al., 2016; Zincir, Ozturk, Bilgen, Izci, & Yukselir, 2016). In 2003, Hestad et al. (Fluitman et al., 2011) reported a decrease in the TNF α level in patients with MDD along with clinical improvement during and after an ECT series, whereas another study revealed a rapid increase in the TNF α level after a single ECT session but no long-term change during the ECT series (Rotter et al., 2013). Other studies have found no change in the TNF α level during or after the ECT series (First et al., 1996; Hestad et al., 2003; Zincir et al., 2016). A recent study revealed a decrease in the TNF α level during and after an ECT series, although the baseline TNF α level before ECT was lower in patients than in controls (Rush et al., 2016).

1.1 | Aims of the study

The causality of the TNF α level and ECT as well as the association between changes in the TNF α level and symptoms during ECT are contradictory. The aim of this study was to examine the changes in the plasma level of TNF α and their possible associations with symptom reduction in patients with MDD at three different sessions during an ECT series. These sessions were included to study the immediate and long-term effects of ECT on the TNF α level during an ECT series. TNF α was measured from plasma (instead of serum) in order to avoid artifact production of TNF alpha during the sampling procedure/clotting process (de Jager, Bourcier, Rijkers, Prakken, & Seyfert-Margolis, 2009).

TABLE 1 Psychotropic medications of patients with MDD during the ECT series

	All patients (n = 30)	Female patients (n = 12)	Male patients (n = 18)
Age			
Mean ± SD	57.1 ± 17.7	71.1 ± 12.2	45.2 ± 17.0
Range	25–85	45–85	25–79
Total number of ECTs			
Mean ± SD	10.4 ± 3.6	10.8 ± 4.3	8.2 ± 3.6
Range	5–17	5–17	5–13
Psychotic symptoms	14	7	7
First episode of MDD	9	4	5
Recurrent MDD	21	13	8
Antidepressants			
SSRI	9	3	6
SNRI	12	5	7
Mirtazapine	12	6	6
Bupropion	4	1	3
Antipsychotics			
Second generation antipsychotics	28	11	17
Conventional neuroleptics	1	0	1
Anxiolytics			
Benzodiazepines	21	8	13
Pregabalin	2	2	0
Buspirone	1	0	1

SSRI, Selective serotonin reuptake inhibitor; SNRI, Serotonin and norepinephrine reuptake inhibitor.

2 | MATERIAL AND METHODS

2.1 | Clinical characteristics

Forty-nine patients with severe or psychotic MDD who were consecutively admitted for ECT to the Department of Psychiatry, Tampere University Hospital were asked to participate in this study. Thirteen of these 49 patients declined, and six patients withdrew from the study. Therefore, the study group comprised 30 patients (12 female, 18 male). On admission, the Structured Clinical Interview for DSM-IV Disorders (American Psychiatric Association, 1994) was conducted to confirm the diagnosis in each patient. All patients fulfilled the DSM-IV diagnostic criteria for MDD (Montgomery & Åsberg, 1979), and 14 of them had psychotic symptoms. Nine patients suffered from a first episode of MDD, and the MDD was recurrent in 21 patients.

Patients with bipolar depression and major psychiatric disorders other than MDD were excluded. Patients with progressive organic brain disorders, epilepsy, inflammatory or autoimmune diseases, and alcohol or other substance abuse were also excluded from the study. Patients who had undergone ECT within 3 months prior to entry into the study were not included.

The mean age of the patients was 57.1 years (standard deviation [SD], 17.7; range, 25–85 years). The patients underwent constant

psychotropic drug treatment throughout the entire ECT period (Table 1). Twenty-eight patients in the study were taking a combination of at least two psychotropic medications, and only two were undergoing monotherapy. Benzodiazepines were discontinued 10 hours before ECT to avoid any effects on the seizure threshold.

The severity of depression was quantified by the Montgomery-Åsberg Depression Rating Scale (MADRS) (Montgomery & Åsberg, 1979) in addition to the TNF α level before the first and after the fifth and last ECT session.

All patients provided written informed consent. This study design was reviewed and approved by the Tampere University Hospital Ethics Committee.

2.2 | Electroconvulsive therapy

Before the first ECT session, a medical history was obtained and a physical examination with routine blood examination and electrocardiogram was performed. ECT was administered three times a week with a constant-current, brief-pulse device (MECTA spECTrum 5000Q; MECTA Corp., Lake Oswego, OR, USA). The seizure threshold was titrated during the first treatment, and subsequent treatments were administered at 1.5 times the seizure threshold for bilateral ECT. Seizures of >25 s in duration on electroencephalography were deemed adequate. If the duration was shorter, a restimulation was

performed during the same treatment session with a 50% increase in the stimulus intensity.

2.3 | Anesthesia

Anesthesia was induced with methohexital (initial dose of 1 mg/kg), and muscle relaxation was achieved with succinylcholine (initial dose of 0.5 mg/kg). The patients were ventilated with 100% oxygen until resumption of spontaneous respiration. Physiological monitoring during the treatment included pulse oximetry, blood pressure, electrocardiography, one-channel electroencephalography and electromyography. All patients were treated with standard bilateral (bifrontotemporal) ECT. The number of treatments ranged from 5 to 17 (10.4 ± 3.6 [mean \pm SD]). ECT treatment was discontinued on the basis of clinical judgment if the patient was either in remission (MADRS score of ≤ 10), or no further improvement was recorded during the last two ECT sessions. In five patients, the fifth ECT session was the last (not included in the last ECT session data).

2.4 | Blood sampling

The blood sampling was strictly standardized. Blood was drawn before ECT (baseline) and 2 and 4 hr after ECT at the first, fifth, and last sessions, and EDTA-treated plasma was separated and stored at -80°C until analyzed. The concentration of TNF α was determined by enzyme-linked immunosorbent assay with commercial reagents (Quantikine HS; R&D Systems Europe, Ltd., Abingdon, UK). The detection limit and interassay coefficient of variation were 0.25 pg/ml and 3.3%, respectively.

2.5 | Statistical methods

A paired-sample *t*-test was used to analyze changes between the TNF α level at different measurement points: baseline vs. 2 hr, baseline vs. 4 hr, and 2 hr vs. 4 hr. The relationships between the TNF α level and symptom reduction according to the MADRS as well as other clinical variables were examined with Spearman's rho due to the skewed distribution in the MADRS response rate variable. Comparisons between responders' and nonresponders' TNF α levels were performed using the Mann-Whitney *U*-test because of the non-normal distribution of

the TNF α levels. A Bonferroni correction was used in the correlation calculation by setting the limit of statistical significance to 0.05/9, that is, by dividing by the number of tests. In all other tests, the level of significance was set at $p < .05$. Spearman's correlation coefficients were used in the exploratory analyses for selecting statistically significant or trend level ($p < .1$) correlating explanatory variables for the regression model to predict dichotomized response, in addition to the included confounding variables age and gender. A logistic regression model was used to predict a dichotomized response. In the model, TNF alpha baseline value, number of ECT treatments, gender, and age were used as explanatory variables. Odds ratios (OR) and 95% confidence intervals (CI) were calculated for covariates. Statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS) version 22.0.

3 | RESULTS

The plasma levels of TNF α during ECT series are presented in Table 2. These levels consistently decreased from baseline (before ECT) to 2 hr during the first ($p < .001$), fifth ($p < .001$), and last ($p = .007$) ECT sessions. The plasma TNF α level also decreased from baseline to 4 hr during every ECT session ($p < .001$, $p < .001$, and $p = .001$, respectively). No significant changes were found in the TNF α level between the 2- and 4-hr measurements. When comparing the baseline TNF α level among the first, fifth, and last ECT sessions, no significant changes were found in the whole study group (Figure 1).

Prior to the first ECT session, the mean MADRS score was 31.6 ± 7.2 (mean \pm SD), and that after the ECT series was 11.3 ± 7.5 . At the end of the study, 22 of 30 patients showed at least a 50% decrease in MADRS score, of those 20 were in remission (MADRS score of ≤ 10). There was a significant correlation between the baseline TNF α level at the first ECT session (prior to ECT series), the 2- and 4-hr TNF α levels, and the relative (%) symptom reduction after the ECT series as reflected by the MADRS score ($\rho = -.588$, $p = .001$; $\rho = -.574$, $p = .001$; $\rho = -.600$, $p < .001$, respectively) (Table 3). Low TNF α concentrations and symptom reduction according to the MADRS score were interrelated (Figure 2). These correlations were inconsistent in subsequent ECT sessions (fifth and last). The TNF α level at both the first ECT session (baseline) and 4 hr

ECT	Measurement	N	Mean	Standard deviation	Range
First	Baseline	30	1.65	0.56	2.42
	2 hr	30	1.42	0.47	1.91
	4 hr	30	1.34	0.43	1.88
Fifth	Baseline	30	1.64	0.45	2.23
	2 hr	30	1.41	0.39	1.76
	4 hr	30	1.48	0.46	1.82
Last	Baseline	25	1.59	0.43	1.70
	2 hr	25	1.42	0.39	1.68
	4 hr	25	1.39	0.43	2.00

TABLE 2 Means, standard deviations, and ranges of plasma TNF α levels during ECT series (pg/ml)

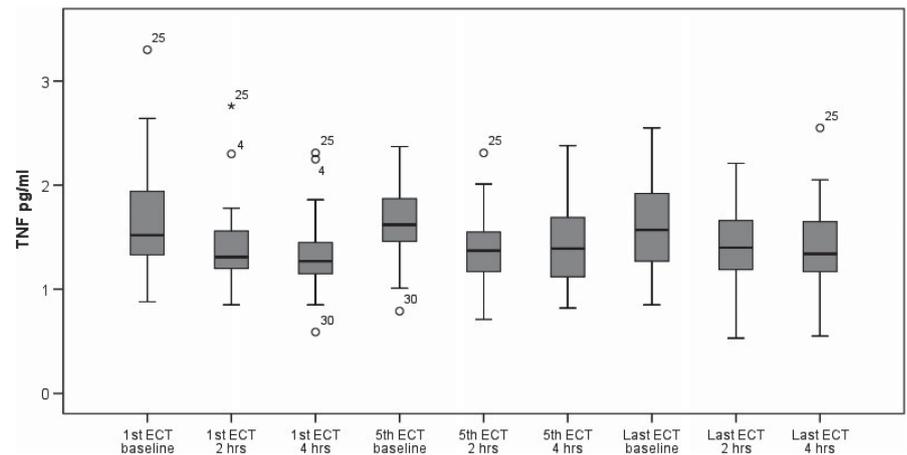


FIGURE 1 Plasma TNF α levels at first, fifth, and last ECT sessions in patients with MDD

TABLE 3 Correlations between plasma TNF α levels and relative (%) symptom reduction in patients with MDD during ECT

ECT	Measurement	rho	<i>p</i>
First	Baseline	-.558	.001*
	2 hr	-.574	.001*
	4 hr	-.600	.001*
Fifth	Baseline	-.283	.130
	2 hr	-.191	.312
	4 hr	-.284	.128
Last	Baseline	-.503	.10
	2 hr	-.390	.054
	4 hr	-.455	.022

*Significant after Bonferroni's correction.

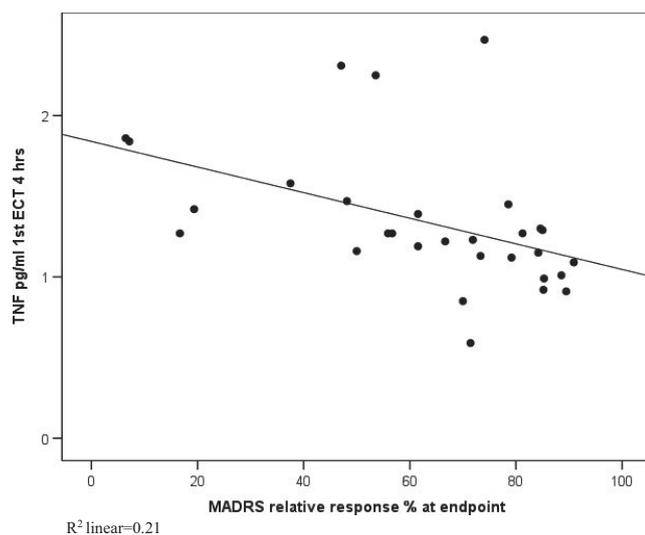


FIGURE 2 First ECT 4-hr TNF α levels and relative symptom reduction in MADRS. R^2 linear = .21

were lower in responders (50% symptom reduction) than in nonresponders ($p = .035$ and $p = .006$, respectively). The dichotomized response had a statistically significant or trend level ($p < .1$) correlation

with smaller number of ECT treatments ($\rho = -.32$, $p = .084$) and with lower baseline TNF α levels ($\rho = -.39$, $p = .032$). The best fitting logistic regression model for predicting the dichotomized response ($p = .03$) included TNF alpha baseline value (OR = 0.20, 95% CI 0.04–1.15, $p = .07$) and number of ECT treatments (OR = 0.76, 95% CI 0.57–1.02, $p = .07$) as explanatory variables. This model explained 31.0% of the outcome variance (Nagelkerke R square); the sensitivity for response was 90.9% and specificity 50%. Gender and age had nonsignificant correlations with the dichotomized response. Neither gender nor age had any predictive effect on the response, and omitting these variables from the model did not change the predictive values.

No correlations were found between clinical parameters (e.g., duration of convulsions, heart rate variability, or changes in blood pressure during ECT) and the TNF α level or clinical outcome.

4 | DISCUSSION

The most interesting finding in the present study was that a low TNF α level at the first ECT (0, 2, and 4 hr) appeared to predict a reduction in symptoms. No similar correlations were found during subsequent sessions. No findings suggesting associations between a low TNF α level and symptom reduction during ECT have been reported in previous studies (First et al., 1996; Fluitman et al., 2011; Hestad et al., 2003; Rotter et al., 2013; Rush et al., 2016; Zincir et al., 2016). If replicated in the future studies, this finding supports the role of TNF α in the pathogenesis of MDD and in the mechanism of action of ECT; it may also guide the selection of treatment modalities for patients with severe MDD. There has been a wide variation in TNF α levels in different studies. However, some of these have reported similar ranges of plasma TNF α levels in depressed patients compared to those in the present study (Dome et al., 2009; O'Donovan et al., 2013).

The decrease in the plasma TNF α level after each session was a consistent finding in the present study. This was observed in every studied session between the baseline measurement and both the 2- and 4-hr measurements. The effect of ECT on the TNF α level appears to be transitory because the TNF α level returned to the basic level

before next ECT session. This finding differs from some previous reports in which the TNF α level either increased, did not change, or decreased by ECT (First et al., 1996; Fluitman et al., 2011; Hestad et al., 2003; Rotter et al., 2013; Rush et al., 2016; Zincir et al., 2016). The design of the study by Hestad et al. (Fluitman et al., 2011) somewhat resembles the design of the present study. In their study, the TNF α level was measured during the ECT series at baseline and 1 hr after the first, fourth, and last ECT session. They reported a decrease in the baseline TNF α level during the ECT series and 24 hr and 1 week after the last ECT session (Fluitman et al., 2011). Additionally, a decrease in the TNF α level was observed in a study in which measurements were taken 1 day before the ECT series, at the time of the clinical response to ECT, and 1 day after the series (Rush et al., 2016). In contrast, Fluitman et al. (Rotter et al., 2013) reported an immediate increase in the TNF α level after every single session of ECT but found no constant change in the baseline TNF α level during the ECT series. The TNF α levels in these two latter studies were serum (not plasma) levels, making comparison with the present results difficult. Moreover, three studies found no change in the serum/plasma/plasma (respectively) TNF α level during and after the ECT series (First et al., 1996; Hestad et al., 2003; Zincir et al., 2016). However, in these studies, the timing of the blood samplings and procedures were somewhat different, hampering comparison with the present results (First et al., 1996; Hestad et al., 2003; Zincir et al., 2016). Unfortunately, the post-ECT TNF α levels (e.g., 1 week after the series) were not available in the present study. However, if we would have observed a persistent decrease in the TNF α level after the ECT series, we would have presumed that this decrease was already apparent in the baseline measurements in different sessions during the ECT series.

Decreases in the TNF α level by anesthetics and muscle relaxant drugs (methohexital and succinylcholine) administered during ECT have been reported in patients with MDD (Stelzhammer et al., 2011). Whether this decrease found in the present study in the TNF α level is related to the anesthetics used or the anti-inflammatory mechanisms of ECT are inconclusive and require further research.

Immune dysregulation and activation of the inflammatory response system are involved with MDD (Miller et al., 2009). Several studies have reported elevated TNF α levels in the blood and cerebrospinal fluid in patients with MDD (Dowlati et al., 2010; Goldsmith et al., 2016; Huang & Lee, 2007; Liu et al., 2012; Martinez, Garakani, Yehuda, & Gorman, 2012; Stelzhammer et al., 2011), but this finding was questioned in a recent meta-analysis (Anisman et al., 1999). However, an elevated TNF- α level has been somewhat associated with severe forms of depression (Anisman et al., 1999). Another meta-analysis of inflammatory biomarkers in patients with MDD undergoing antidepressant treatment reported no decrease in the elevated baseline TNF α level. In that report, however, there was a decrease in the TNF α level in responders compared with nonresponders (Köhler et al., 2017).

The main limitation of the present study is the relatively small sample size. Additionally, the lack of healthy controls hampered the interpretation of the results. Circulating TNF α levels are affected by various metabolic and pathological conditions in addition to MDD (McArdle, Finucane, Connaughton, McMorrow, & Roche, 2013; Sinha et al.,

2013). Moreover, plasma TNF α levels may be affected by anesthesia during ECT series (Stelzhammer et al., 2011). Even though the dichotomized response correlated significantly with lower baseline TNF α levels, these levels predicted the dichotomized response only at trend level in the logistic regression model. The association should therefore be confirmed in a larger sample. The baseline (before any treatment) TNF α levels used here, however, reflect only the influence of the disorder (MDD), not the effect of ECT. The strengths of this study include the standardized timing of repeated blood sampling during the individual ECT sessions and throughout the ECT series, which improves the reliability of the results. Thus, the effects of both the disorder (MDD) and the treatment (ECT) on TNF α levels have been considered.

In conclusion, low TNF α levels before and after the first ECT session predict symptom reduction after the ECT series. Every individual ECT session seemed to decrease the plasma TNF α level at 2 and 4 hr compared with baseline. This effect, however, was transitory because the baseline level did not change between the sessions. The predictive value of the first ECT session TNF α levels associated with final symptom reduction would be clinically interesting, if replicated in the further studies.

ACKNOWLEDGMENTS

Ms. Terhi Salonen is warmly acknowledged for her excellent technical assistance. This study was funded by grants from the Competitive Research Funding of Tampere University Hospital.

CONFLICTS OF INTEREST

None declared.

ORCID

Annamari Sorri  <http://orcid.org/0000-0002-3565-2805>

REFERENCES

- Abbasi, S., Hosseini, F., Modabbernia, A., Ashrafi, M., & Akhondzadeh, S. (2012). Effect of celecoxib add-on treatment on symptoms and serum IL-6 concentrations in patients with major depressive disorder: Randomized double-blind placebo-controlled study. *Journal of Affective Disorders, 141*, 308–314. <https://doi.org/10.1016/j.jad.2012.03.033>
- Akhondzadeh, S., Jafari, S., Raisi, F., Nasehi, A. A., Ghoreishi, A., Salehi, B., ... Kamalipour, A. (2009). Clinical trial of adjunctive celecoxib treatment in patients with major depression: A double blind and placebo controlled trial. *Depression and Anxiety, 26*, 607–611. <https://doi.org/10.1002/da.20589>
- American Psychiatric Association (1994). *Diagnostic and statistical manual of mental disorders*, 4th ed. Washington DC: American Psychiatric Press.
- American Psychiatric Association (2001). *The practice of electroconvulsive therapy: Recommendations for treatment, training and privileging: A task force report of the American Psychiatric Association*. Washington DC: American Psychiatric Association.
- Anisman, H., Ravindran, A. V., Griffiths, J., & Merali, Z. (1999). Endocrine and cytokine correlates of major depression and dysthymia with

- typical or atypical features. *Molecular Psychiatry*, 4, 182–188. <https://doi.org/10.1038/sj.mp.4000436>
- Bizik, G., Bob, P., Raboch, J., Pavlat, J., Uhrova, J., Benakova, H., & Zima, T. (2014). Dissociative symptoms reflect levels of tumor necrosis factor alpha in patients with unipolar depression. *Neuropsychiatric Disease and Treatment*, 10, 675–679. <https://doi.org/10.2147/NDT>
- Bonaccorso, S., Marino, V., Biondi, M., Grimaldi, F., Ippoliti, F., & Maes, M. (2002). Depression induced by treatment with interferon-alpha in patients affected by hepatitis C virus. *Journal of Affective Disorders*, 72, 237–241. [https://doi.org/10.1016/S0165-0327\(02\)00264-1](https://doi.org/10.1016/S0165-0327(02)00264-1)
- Bonaccorso, S., Puzella, A., Marino, V., Pasquini, M., Biondi, M., Artini, M., ... Maes, M. (2001). Immunotherapy with interferon-alpha in patients affected by chronic hepatitis C induces an intercorrelated stimulation of the cytokine network and an increase in depressive and anxiety symptoms. *Psychiatry Research*, 105, 45–55. [https://doi.org/10.1016/S0165-1781\(01\)00315-8](https://doi.org/10.1016/S0165-1781(01)00315-8)
- Capuron, L., Ravaut, A., & Dantzer, R. (2001). Timing and specificity of the cognitive changes induced by interleukin-2 and interferon-alpha treatments in cancer patients. *Psychosomatic Medicine*, 63, 376–386. <https://doi.org/10.1097/00006842-200105000-00007>
- Capuron, L., Ravaut, A., Gualde, N., Bosmans, E., Dantzer, R., Maes, M., & Neveu, P. J. (2001). Association between immune activation and early depressive symptoms in cancer patients treated with interleukin-2-based therapy. *Psychoneuroendocrinology*, 26, 797–808. [https://doi.org/10.1016/S0306-4530\(01\)00030-0](https://doi.org/10.1016/S0306-4530(01)00030-0)
- Dantzer, R., O'Connor, J. C., Lawson, M. A., & Kelley, K. W. (2011). Inflammation-associated depression: From serotonin to kynurenine. *Psychoneuroendocrinology*, 36, 426–436. <https://doi.org/10.1016/j.psyneuen.2010.09.012>
- Dieperink, E., Willenbring, M., & Ho, S. B. (2000). Neuropsychiatric symptoms associated with hepatitis C and interferon alpha: A review. *American Journal of Psychiatry*, 157, 867–876. <https://doi.org/10.1176/appi.ajp.157.6.867>
- Dome, P., Teleki, Z., Rihmer, Z., Peter, L., Dobos, J., Kenessey, I., ... Dome, B. (2009). Circulating endothelial progenitor cells and depression: A possible novel link between heart and soul. *Molecular Psychiatry*, 14, 523–531. <https://doi.org/10.1038/sj.mp.4002138>
- Dowlati, Y., Herrmann, N., Swardfager, W., Liu, H., Sham, L., Reim, E. K., & Lancôt, K. L. (2010). A meta-analysis of cytokines in major depression. *Biological Psychiatry*, 67, 446–457. <https://doi.org/10.1016/j.biopsych.2009.09.033>
- Dunn, A. J., Swiergiel, A. H., & de Beurepaire, R. (2005). Cytokines as mediators of depression: What can we learn from animal studies? *Neuroscience and Biobehavioral Reviews*, 29, 891–909. <https://doi.org/10.1016/j.neubiorev.2005.03.023>
- First, M., Spitzer, R., Gibbon, M., & Williams, J. (1996). *Structured clinical interview for DSM-IV axis I disorders, clinician version (SCID-CV)*. Washington DC: American Psychiatric Press Inc.
- Fluitman, S. B., Heijnen, C. J., Denys, D. A., Nolen, W. A., Balk, F. J., & Westenberg, H. G. (2011). Electroconvulsive therapy has acute immunological and neuroendocrine effects in patients with major depressive disorder. *Journal of Affective Disorders*, 131, 388–392. <https://doi.org/10.1016/j.jad.2010.11.035>
- Goldsmith, D., Rapaport, M., & Miller, B. (2016). A meta-analysis of blood cytokine network alterations in psychiatric patients: Comparisons between schizophrenia, bipolar disorder and depression. *Molecular Psychiatry*, 21, 1696–1709. <https://doi.org/10.1038/mp.2016.3>
- Goshen, I., Kreisel, T., Ben-Menachem-Zidon, O., Licht, T., Weidenfeld, J., Ben-Hur, T., & Yirmiya, R. (2008). Brain interleukin-1 mediates chronic stress-induced depression in mice via adrenocortical activation and hippocampal neurogenesis suppression. *Molecular Psychiatry*, 13, 717–728. <https://doi.org/10.1038/sj.mp.4002055>
- Guloksuz, S., Arts, B., Walter, S., Drukker, M., Rodriguez, L., Myint, A. M., ... Rutten, B. P. (2015). The impact of electroconvulsive therapy on the tryptophan-kynurenine metabolic pathway. *Brain, Behavior, and Immunity*, 48, 48–52. <https://doi.org/10.1016/j.bbi.2015.02.029>
- Haapakoski, R., Mathieu, J., Ebmeier, K. P., Alenius, H., & Kivimäki, M. (2015). Cumulative meta-analysis of interleukins 6 and 1 β , tumour necrosis factor α and C-reactive protein in patients with major depressive disorder. *Brain, Behavior, and Immunity*, 49, 206–215. <https://doi.org/10.1016/j.bbi.2015.06.001>
- Haron, E., Raison, C. L., & Miller, A. H. (2012). Psychoneuroimmunology meets neuropsychopharmacology: Translational implications of the impact of inflammation on behavior. *Neuropsychopharmacology*, 37, 137–162. <https://doi.org/10.1038/npp.2011.205>
- Harrison, N. A., Brydon, L., Walker, C., Gray, M. A., Steptoe, A., & Critchley, H. D. (2009). Inflammation causes mood changes through alterations in subgenual cingulate activity and mesolimbic connectivity. *Biological Psychiatry*, 66, 407–414. <https://doi.org/10.1016/j.biopsych.2009.03.015>
- Hestad, K. A., Tønseth, S., Støen, C. D., Ueland, T., & Aukrust, P. (2003). Raised plasma levels of tumor necrosis factor alpha in patients with depression: Normalization during electroconvulsive therapy. *The Journal of ECT*, 19, 183–188. <https://doi.org/10.1097/00124509-200312000-00002>
- Huang, T., & Lee, C. (2007). T-helper 1/T-helper 2 cytokine imbalance and clinical phenotypes of acute-phase major depression. *Psychiatry and Clinical Neurosciences*, 61, 415–420. <https://doi.org/10.1111/j.1440-1819.2007.01686.x>
- de Jager, W. I., Bourcier, K., Rijkers, G. T., Prakken, B. J., & Seyfert-Margolis, V. (2009). Prerequisites for cytokine measurements in clinical trials with multiplex immunoassays. *BMC Immunology*, 10, 52–63. <https://doi.org/10.1186/1471-2172-10-52>
- Janelidze, S., Mattei, D., Westrin, Å., Träskman-Benz, L., & Brundin, L. (2011). Cytokine levels in the blood may distinguish suicide attempters from depressed patients. *Brain, Behavior, and Immunity*, 25, 335–339. <https://doi.org/10.1016/j.bbi.2010.10.010>
- Kargar, M., Yousefi, A., Mojtahedzadeh, M., Akhondzadeh, S., Artounian, V., Abdollahi, A., ... Ghaeli, P. (2014). Effects of celecoxib on inflammatory markers in bipolar patients undergoing electroconvulsive therapy: A placebo-controlled, double-blind, randomised study. *Swiss Medical Weekly*, 144, w13880.
- Karlovic, D., Serretti, A., Vrkic, N., Martinac, M., & Marcinko, D. (2012). Serum concentrations of CRP, IL-6, TNF- α and cortisol in major depressive disorder with melancholic or atypical features. *Psychiatry Research*, 198, 74–80. <https://doi.org/10.1016/j.psychres.2011.12.007>
- Khairova, R. A., Machado-Vieira, R., Du, J., & Manji, H. K. (2009). A potential role for pro-inflammatory cytokines in regulating synaptic plasticity in major depressive disorder. *International Journal of Neuropsychopharmacology*, 12, 561–578. <https://doi.org/10.1017/S1461145709009924>
- Köhler, C. A., Freitas, T. H., Maes, M., de Andrade, N. Q., Liu, C. S., Fernandes, B. S., ... Carvalho, A. F. (2017). Peripheral cytokine and chemokine alterations in depression: A meta-analysis of 82 studies. *Acta Psychiatrica Scandinavica*, 135, 373–387. <https://doi.org/10.1111/acps.12698>
- Lamers, F., Vogelzangs, N., Merikangas, K. R., de Jonge, P., Beekman, A. T. F., & Penninx, B. W. J. H. (2013). Evidence for a differential role of HPA-axis function, inflammation and metabolic syndrome in melancholic versus atypical depression. *Molecular Psychiatry*, 18, 692–699. <https://doi.org/10.1038/mp.2012.144>
- Lawson, M. A., McCusker, R. H., & Kelley, K. W. (2013). Interleukin-1 beta converting enzyme is necessary for development of depression-like behavior following intracerebroventricular administration of lipopolysaccharide to mice. *Journal of Neuroinflammation*, 10, 54.
- Liu, Y., Ho, R. C., & Mak, A. (2012). Interleukin (IL)-6, tumour necrosis factor alpha (TNF- α) and soluble interleukin-2 receptors (sIL-2R) are elevated in patients with major depressive disorder: A meta-analysis and meta-regression. *Journal of Affective Disorders*, 139, 230–239. <https://doi.org/10.1016/j.jad.2011.08.003>

- Maes, M. (1995). Evidence for an immune response in major depression: A review and hypothesis. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *19*, 11–38. [https://doi.org/10.1016/0278-5846\(94\)00101-M](https://doi.org/10.1016/0278-5846(94)00101-M)
- Maes, M., Mihaylova, I., Kubera, M., & Ringel, K. (2012). Activation of cell-mediated immunity in depression: Association with inflammation, melancholia, clinical staging and the fatigue and somatic symptom cluster of depression. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *36*, 169–175. <https://doi.org/10.1016/j.pnpbp.2011.09.006>
- Martinez, J. M., Garakani, A., Yehuda, R., & Gorman, J. M. (2012). Proinflammatory and “resiliency” proteins in the CSF of patients with major depression. *Depression and Anxiety*, *29*, 32–38. <https://doi.org/10.1002/da.20876>
- McArdle, M. A., Finucane, O. M., Connaughton, R. M., McMorrow, A. M., & Roche, H. M. (2013). Mechanisms of obesity-induced inflammation and insulin resistance: Insights into the emerging role of nutritional strategies. *Frontiers in Endocrinology*, *4*, 1–23.
- Miller, A. H., Maletic, V., & Raison, C. L. (2009). Inflammation and its discontents: The role of cytokines in the pathophysiology of major depression. *Biological Psychiatry*, *65*, 732–741. <https://doi.org/10.1016/j.biopsych.2008.11.029>
- Montgomery, S., & Åsberg, M. (1979). A new depression scale designed to be sensitive to change. *British Journal of Psychiatry*, *134*, 382–389. <https://doi.org/10.1192/bjp.134.4.382>
- Müller, N., Schwarz, M. J., Dehning, S., Douhe, A., Cerovecki, A., Goldstein-Müller, B., ... Riedel, M. (2006). The cyclooxygenase-2 inhibitor celecoxib has therapeutic effects in major depression: Results of a double-blind, randomized, placebo controlled, add-on pilot study to reboxetine. *Molecular Psychiatry*, *11*, 680–684. <https://doi.org/10.1038/sj.mp.4001805>
- Myint, A. M., & Kim, Y. K. (2003). Cytokine-serotonin interaction through IDO: A neurodegeneration hypothesis of depression. *Medical Hypotheses*, *61*, 519–525. [https://doi.org/10.1016/S0306-9877\(03\)00207-X](https://doi.org/10.1016/S0306-9877(03)00207-X)
- O’Donovan, A., Rush, G., Hoatam, G., Hughes, B. M., McCrohan, A., Kelleher, C., ... Malone, K. M. (2013). Suicidal ideation is associated with elevated inflammation in patients with major depressive disorder. *Depression and Anxiety*, *30*, 307–314. <https://doi.org/10.1002/da.22087>
- Rotter, A., Biermann, T., Stark, C., Decker, A., Demling, J., Zimmermann, R., ... Henkel, A. (2013). Changes of cytokine profiles during electroconvulsive therapy in patients with major depression. *The Journal of ECT*, *29*, 162–169. <https://doi.org/10.1097/YCT.0b013e3182843942>
- Rush, G., O’Donovan, A., Nagle, L., Conway, C., McCrohan, A., O’Farrelly, C., ... Malone, K. M. (2016). Alteration of immune markers in a group of melancholic depressed patients and their response to electroconvulsive therapy. *Journal of Affective Disorders*, *205*, 60–68. <https://doi.org/10.1016/j.jad.2016.06.035>
- Schwarcz, R., Bruno, J. P., Muchowski, P. J., & Wu, H. (2012). Kynurenines in the mammalian brain: When physiology meets pathology. *Nature Reviews Neuroscience*, *13*, 465–477. <https://doi.org/10.1038/nrn3257>
- Schwieler, L., Samuelsson, M., Frye, M. A., Bhat, M., Schuppe-Koistinen, I., Jungholm, O., ... Erhardt, S. (2016). Electroconvulsive therapy suppresses the neurotoxic branch of the kynurenine pathway in treatment-resistant depressed patients. *Journal of Neuroinflammation*, *13*, 51. <https://doi.org/10.1186/s12974-016-0517-7>
- Sinha, K., Das, J., Pal, P. B., & Sil, P. C. (2013). Oxidative stress: The mitochondria-dependent and mitochondria-independent pathways of apoptosis. *Archives of Toxicology*, *87*, 1157–1180. <https://doi.org/10.1007/s00204-013-1034-4>
- Stelzhammer, V., Rothermundt, M., Guest, P. C., Michael, N., Sondermann, C., Kluge, W., ... Bahn, S. (2011). Proteomic changes induced by anaesthesia and muscle relaxant treatment prior to electroconvulsive therapy. *Proteomics. Clinical Applications*, *5*, 644–649. <https://doi.org/10.1002/prca.201100040>
- Strawbridge, R., Arnone, D., Danese, A., Papadopoulos, A., Herane Vives, A., & Cleare, A. J. (2015). Inflammation and clinical response to treatment in depression: A meta-analysis. *European Neuropsychopharmacology*, *25*, 1532–1543. <https://doi.org/10.1016/j.euroneuro.2015.06.007>
- UK ECT Review Group (2003). Efficacy and safety of electroconvulsive therapy in depressive disorders: A systematic review and meta-analysis. *Lancet*, *361*, 799–808.
- Yirmiya, R., & Goshen, I. (2011). Immune modulation of learning, memory, neural plasticity and neurogenesis. *Brain, Behavior, and Immunity*, *25*, 181–213. <https://doi.org/10.1016/j.bbi.2010.10.015>
- Yoon, H., Kim, Y., Lee, H., Kwon, D., & Kim, L. (2012). Role of cytokines in atypical depression. *Nordic Journal of Psychiatry*, *66*, 183–188. <https://doi.org/10.3109/08039488.2011.611894>
- Zincir, S., Ozturk, P., Bilgen, A., Izci, F., & Yukselir, C. (2016). Levels of serum immunomodulators and alterations with electroconvulsive therapy in treatment-resistant major depression. *Neuropsychiatric Disease and Treatment*, *12*, 1389–1396. <https://doi.org/10.2147/NDT>

How to cite this article: Sorri A, Järventausta K, Kampman O, et al. Low tumor necrosis factor- α levels predict symptom reduction during electroconvulsive therapy in major depressive disorder. *Brain Behav.* 2018;8:e00933. <https://doi.org/10.1002/brb3.933>