

The Relation of Interleukin 17 (IL-17) and IL-23 to Th1 /Th2 Cytokines and Disease Activity in Systemic Lupus Erythematosus

MO YIN MOK, HAI JING WU, YI LO, and CHAK SING LAU

ABSTRACT. Objective. Interleukin 17 (IL-17) was recently linked to pathogenesis of systemic lupus erythematosus (SLE), but its relation to disease activity has not been well characterized. We examined the relation between serum levels of Th17 (IL-17, IL-23), Th1 (IL-12, interferon- γ), Th2 (IL-10, IL-6, IL-4) cytokines and disease activity in patients with SLE.

Methods. Serum cytokines were measured by enzyme linked immunosorbent assays. Disease activity was determined by SLE disease activity index (SLEDAI), anti-dsDNA antibody, and C3 and C4 levels.

Results. Serum levels of IL-17 ($p < 0.001$), IL-6 ($p = 0.006$) and IL-10 ($p < 0.001$) were higher in SLE patients ($n = 70$) compared to healthy controls ($n = 36$). Higher serum IL-23 level was found in patients with active disease with cutaneous manifestations ($p = 0.004$) and serositis ($p = 0.04$) compared to those without. Serum IL-17 level above the detection limit was more frequently found in patients who had active lupus nephritis (11/23, 47.8%) ($p = 0.002$), nonrenal active disease (9/15, 60%) ($p = 0.001$), and inactive lupus (21/32, 65.6%) ($p < 0.001$) compared to healthy controls (0%). Serum IL-17 levels were otherwise comparable between these 3 groups of patients and were not related to SLEDAI, glomerular filtration rate, activity or chronicity score and ISN/RPS criteria class among patients with active lupus nephritis. There was no significant correlation between serum IL-17/IL-23 and Th1 or Th2 cytokine levels.

Conclusion. SLE patients had higher serum IL-17 levels than healthy controls. Elevated serum IL-23 was found in patients with inflammatory manifestations including cutaneous involvement and serositis. The lack of correlation between Th17, Th1, and Th2 cytokines suggested independent regulatory mechanisms for these cytokines. (J Rheumatol First Release August 1 2010; doi:10.3899/jrheum.100293)

Key Indexing Terms:

CYTOKINES

SYSTEMIC LUPUS ERYTHEMATOSUS

DISEASE ACTIVITY

T cell mediated immune response has traditionally been believed to be controlled by T-helper 1 (Th1) and Th2 cells¹. Th17 cells have recently been identified to be a new subset of T-helper effector cells with a distinct requirement of inducing cytokines and transcription factor for differentiation and produce interleukin 17 (IL-17), their signature cytokine^{2,3}. The differentiation of Th17 cells excludes the acquisition of Th1 or Th2 phenotypes. The transcription factor, retinoid-related orphan receptor (ROR γ t), is expressed exclusively in Th17 cells⁴. IL-23, a cytokine of the IL-12 family, has been found to play a crucial role in the expansion

and maintenance of Th17 cells and mediates the full acquisition of pathogenic function of these cells⁵. IL-17 has been shown to induce other proinflammatory cytokines such as IL-6, IL-21, IL-22, chemokines, and acute-phase proteins⁶ and has been associated with the pathogenesis of many inflammatory diseases such as rheumatoid arthritis⁷, psoriasis⁸, and inflammatory bowel disease⁹.

Systemic lupus erythematosus (SLE) is an autoimmune disease characterized by organ inflammation secondary to immune-complex deposition. IL-17 has recently been linked to pathogenesis of a murine model of SLE as well as human lupus¹⁰, making this cytokine an appealing target for therapy. Elevated serum IL-17 in SLE patients has been described^{11,12,13,14} but the relation of cytokines from the IL-17/IL-23 axis to other Th1/Th2 cytokines and lupus disease activity has not been well established. We examined serum levels of IL-17 and IL-23 and their relation to Th1/Th2 cytokines and parameters of lupus disease activity.

MATERIALS AND METHODS

Patients and controls. Our study was approved by the ethics committee of

From the Division of Rheumatology and Clinical Immunology, Department of Medicine, Queen Mary Hospital, Hong Kong.

Supported by Seed Funding Programme for Basic Research (20084159001) from the University of Hong Kong.

M.Y. Mok, FRCP, FRCPA, Assistant Professor; H.J. Wu, BSc (Immunology), PhD Student; Y. Lo, MBChB, Research Assistant; C.S. Lau, MBChB, MD, FRCP, Professor, Department of Medicine, Queen Mary Hospital, University of Hong Kong.

Address correspondence to Dr. Mok. E-mail: temy@hkucc.hku.hk Accepted for publication May 31, 2010.

Personal non-commercial use only. The Journal of Rheumatology Copyright © 2010. All rights reserved.

the Institutional Review Board of The University of Hong Kong/Hospital Authority Hong Kong West Cluster. Patients who satisfied the American College of Rheumatology revised classification criteria for SLE¹⁵ were recruited from a University affiliated Lupus clinic. Age- and sex-matched volunteers were recruited from staff clinic as normal controls. Written informed consent was obtained from all participating subjects according to the Declaration of Helsinki. Patient information in regard to demographic data, cumulative clinical features, serological profile, and medications were retrieved from medical records. Physical examination and laboratory investigations including complete blood count, liver and renal functions, levels of anti-dsDNA antibody, complements C3 and C4 were performed at study visit. Disease activity was determined according to SLE disease activity index (SLEDAI)¹⁶. Active lupus disease was defined as SLEDAI > 6 in this study. Patients who developed significant proteinuria > 0.5 g/day, serum albumin < 35 g/l, active urinary sediments, and/or renal biopsy proven lupus nephritis at the time of study were regarded as having active renal involvement. Renal biopsy proven lupus nephritis was interpreted according to the International Society of Nephrology/Renal Pathology Society (ISN/RPS) classification criteria¹⁷ with activity and chronicity index reported. Hematological involvement was defined as presence of autoimmune hemolytic anemia, leukopenia with white blood cell < 3.0 × 10⁹/l, or thrombocytopenia with platelets < 150 × 10⁹/l. Renal function was evaluated by estimated glomerular filtration rate (eGFR) using Modification of Diet in Renal Disease formula¹⁸ where

$$eGFR = 32788 \times \text{serum creatinine}^{-1.154} \times \text{age}^{-0.203} \times [0.742 \text{ for female}]$$

Impaired renal function was defined as eGFR < 60 ml/min/1.73 m² (ref¹⁹). Serum level of anti-dsDNA antibody was measured by inhouse ELISA using a calibration curve generated from 6 standards that were prepared with reference to the World Health Organization international standard serum Wo80. The interassay coefficient of variation of the immunoassay for low and high controls was 14.7% and 6.7%, respectively. Serum C3 and C4 levels were determined by immunonephelometry (Image 800, Beckman Coulter, USA). Their corresponding lower normal limits were defined as 76 mg/dl and 9 mg/dl, respectively.

Immunoassay of cytokines. Ten ml of peripheral blood was collected from patients and controls and stored at -70°C for subsequent measurement of cytokines. Serum samples were collected before increase in dose of corticosteroid or immunosuppressive drugs for patients with active disease. Th1 [interferon-γ (IFN-γ), IL-12], Th2 (IL-10, IL-4, IL-6) and Th17 (IL-17, IL-23) related cytokines were measured by ELISA. Serum IL-17 and IL-23 were determined using ELISA kits from R&D Systems (Minneapolis, MN, USA) and BenderMedSystems (Vienna, Austria), respectively, whereas IL-4, IL-6, IL-10, IL-12 and IFN-γ were assayed using kits from eBioscience (San Diego, CA, USA). The detection limits for IFN-γ, IL-12p70, IL-10, IL-4, IL-6, IL-17, and IL-23 are 4 pg/ml, 4 pg/ml, 2 pg/ml, 2 pg/ml, 2 pg/ml, 15 pg/ml and 10 pg/ml, respectively.

Statistical analysis. Data analysis was performed by SPSS 16.0 (Chicago, IL, USA). Data were presented as mean ± standard deviation (SD) or median for the various cytokines as their distribution was highly skewed. Mann-Whitney U test, and analysis of variance (ANOVA) where appropriate, was used to compare continuous variables between groups. Spearman's correlation was used for correlation analysis. A p value of < 0.05 was taken as statistically significant.

RESULTS

Demographics. Seventy patients with SLE (65 female, 5 male) and 36 healthy controls (32 female, 4 male) were recruited. The mean ± SD age of these patients were 45.2 ± 12.2 years with disease duration of 12.9 ± 8.0 years. Table 1 shows the demographics and clinical characteristics of these patients. Thirty-six patients had active disease with SLEDAI

Table 1. Cumulative clinical features and clinical manifestations at the time of study of SLE patients.

Characteristics	SLE, n = 70
Female: male, no.	65:5
Age at study, yrs*	45.0 ± 12.0
Duration of disease, yrs*	12.9 ± 8.0
Clinical manifestations, no. (%)	
Arthritis/arthralgia	7 (10.0)
Oral ulcer	10 (14.3)
Malar rash	5 (7.1)
Cutaneous vasculitis	6 (8.6)
Serositis	6 (8.6)
Autoimmune hemolytic anemia	4 (5.7)
Leukopenia	3 (4.3)
Lymphopenia	46 (78.0)
Immune thrombocytopenia	5 (7.1)
Renal involvement	23 (32.9)
Nervous system involvement	3 (4.3)
SLEDAI score*	12.3 ± 4.6 (range 8–24)
Active disease, SLEDAI > 6 (%)	36 (51.4)
Serological features	
Antinuclear antibody, no. (%)	68 (97.1)
Elevated anti-dsDNA antibody, > 30 IU/ml (%)	43 (61.4)
Low serum C3, < 76 mg/dl	44 (62.9)
Low serum C4, < 9 mg/dl	25 (35.7)
Medications	
Prednisolone	46 (65.7)
Hydroxychloroquine	33 (47.1)
Azathioprine	30 (42.9)
Mycophenolate mofetil	11 (15.7)

* Mean ± standard deviation.

of 12.3 ± 4.6 (range 8–24). Twenty-three patients had active lupus nephritis, 15 patients had non-renal active lupus disease whereas 32 patients had inactive disease. Renal biopsy was performed in 17 of the 23 patients with active lupus nephritis. Class IV lupus nephritis was found in 8 patients, mixed Class IV and V in 6, and Class III in 3 patients. The activity and chronicity scores were 7.3 ± 3.7 and 2.4 ± 2.0, respectively. Among patients with non-renal active disease, 7 patients had cutaneous manifestations, 5 had arthritis, 3 had hematological involvement, 3 had serositis, and 1 had cerebral lupus. Sixty-six percent of patients were receiving a median dose of prednisolone at 6.3 mg daily whereas 47.1%, 42.9%, and 15.7% of patients were receiving hydroxychloroquine, azathioprine, and mycophenolate mofetil with median dose of 200 mg, 75 mg, and 1000 mg daily, respectively, among those taking these medications.

Serum levels of Th1, Th2, and Th17 cytokines in SLE versus controls. Th1 (IFN-γ, IL-12), Th2 (IL-10, IL-4, IL-6), and Th17 (IL-17, IL-23) related cytokines were measured by ELISA in serum from patients and healthy subjects. SLE patients were found to have significantly higher median serum levels of IL-10 (5.2 vs 3.2 pg/ml, p < 0.001) and IL-6 (3.1 vs 2.2 pg/ml, p = 0.006) but comparable IFN-γ (p = 0.61), IL-12 (p = 1.00), and IL-4 (p = 0.37) levels compared to controls. In regard to Th17 related cytokines, patients

with SLE were found to have significantly higher serum IL-17 level (14.8 pg/ml) than normal controls (4.5 pg/ml) ($p < 0.001$). Serum IL-23 level was not found to be different between lupus patients (31.2 vs 30.5 pg/ml) and healthy subjects ($p = 0.87$).

Serum levels of Th1, Th2, and Th17 cytokines in relation to organ involvement. Among patients who had active disease, serum IL-17 level was not found to be related to particular organ involvement including cutaneous ($p = 0.18$), arthritis ($p = 0.97$), hematological ($p = 0.69$), serositis ($p = 0.05$), renal ($p = 0.20$) or neurological ($p = 0.19$) involvement compared to patients who did not have these manifestations (Table 2). On the other hand, patients who had arthritis were noted to have higher serum levels of IFN- γ (12.1 vs 6.6 pg/ml, $p = 0.045$) and lower IL-4 (1.9 vs 2.7 pg/ml, $p = 0.04$) compared to those who did not have arthritis. Patients who had cutaneous involvement (33.9 vs 27.6 pg/ml, $p = 0.004$) and those who had serositis (36.2 vs 27.6 pg/ml, $p = 0.03$) were found to have higher serum IL-23 levels compared to patients who did not have these manifestations. Other cytokines were not found to be related to particular organ involvement among patients with active disease. There were no significant clinical associations of these cytokines among all SLE patients (data not shown).

Serum levels of Th1, Th2, and Th17 cytokines in relation to overall disease activity. Patients with SLE who had active disease were found to have higher serum level of IL-10 (6.8 vs 4.8 pg/ml) compared to those who had inactive disease ($p = 0.001$). Serum IL-17 (14.8 vs 14.8 pg/ml, $p = 0.25$) and IL-23 (30.3 vs 31.6 pg/ml, $p = 0.11$) levels were comparable between active and inactive patients. Serum levels of IL-12, IL-6, IL-4, and IFN- γ were not different between these 2 groups of patients.

SLEDAI was not found to correlate with serum levels of

IL-17 ($r = -0.17$, $p = 0.17$) or IL-23 ($r = -0.10$, $p = 0.42$). IL-10 was the only cytokine found to correlate with SLEDAI ($r = 0.57$, $p < 0.001$) and was higher in patients who had elevated serum anti-dsDNA antibody (6.8 vs 4.7 pg/ml, $p = 0.001$), and low serum C3 (7.1 vs 4.7 pg/ml, $p = 0.001$) and C4 (9.1 vs 4.9 pg/ml, $p = 0.002$) compared to those with lesser disease activity. Neither IL-17 nor IL-23 was associated with these serological markers of lupus activity. There was a trend of negative correlation between serum IL-17 with peripheral lymphocyte count ($r = -0.21$, $p = 0.08$).

Serum levels of Th1, Th2, and Th17 cytokines in patients with active lupus nephritis. ANOVA analysis showed significant differences in serum levels of IL-17 ($p < 0.001$) and IL-10 ($p < 0.001$) between patients who had active lupus nephritis, non-renal active disease, and inactive lupus, and normal controls. The median serum IL-17 levels in these subjects were 14.0, 17.1, 14.8, and 4.5 pg/ml, respectively, (Figure 1A). There were more patients with measurable serum IL-17 levels above detection limit of the immunoassay among patients with active lupus nephritis (11/23, 47.8%) ($p = 0.002$), non-renal active disease (9/15, 60%) ($p = 0.001$), and inactive lupus (21/32, 65.6%) ($p < 0.001$) compared to healthy controls (0/36, 0%). Serum IL-17 levels were otherwise not different between patients with active lupus nephritis, non-renal active disease, and inactive disease ($p = 0.29$ by ANOVA).

Serum IL-17 levels were not found to correlate with renal SLEDAI ($p = 0.11$) and eGFR ($p = 0.12$) in all SLE patients. Among patients who had active lupus nephritis, serum IL-17 was not found to correlate with amount of proteinuria ($r = -0.17$, $p = 0.45$), activity score ($p = 0.76$), or chronicity score ($p = 0.28$) from renal biopsy. Patients who had class IV lupus nephritis did not differ in their serum IL-17 levels compared to those who had non-Class IV lupus nephritis (p

Table 2. Median serum interleukin 17 (IL-17) levels according to internal organ involvement among patients with active SLE.

Clinical Features	Serum IL-17, pg/ml		
	Present	Absent	p
Arthritis	14.0	14.8	0.97
Cutaneous manifestation	14.0	14.8	0.18
Serositis	11.1	14.8	0.05
Hematological involvement	14.0	14.8	0.69
Nervous system involvement	17.1	14.8	0.19
Active lupus nephritis (range)	14.0 (8.3–24.0)	17.1 (7.5–39.9)	0.20
eGFR < 60 ml/min/1.73 m ²	14.8	14.8	0.58
Serum albumin < 35 g/l	14.4	16.0	0.25
Proteinuria > 0.5 g/day	14.0	17.1	0.26
ISN/RPS Class IV nephritis	14.2	14.0	0.59
Increased anti-dsDNA antibody binding	14.8	14.8	0.74
C3 < 76 mg/dl	14.8	12.3	0.60
C4 < 9 mg/dl	14.0	14.8	0.71

eGFR: estimated glomerular filtration rate; ISN/RPS: International Society of Nephrology/Renal Pathology Society (ISN/RPS) classification criteria.

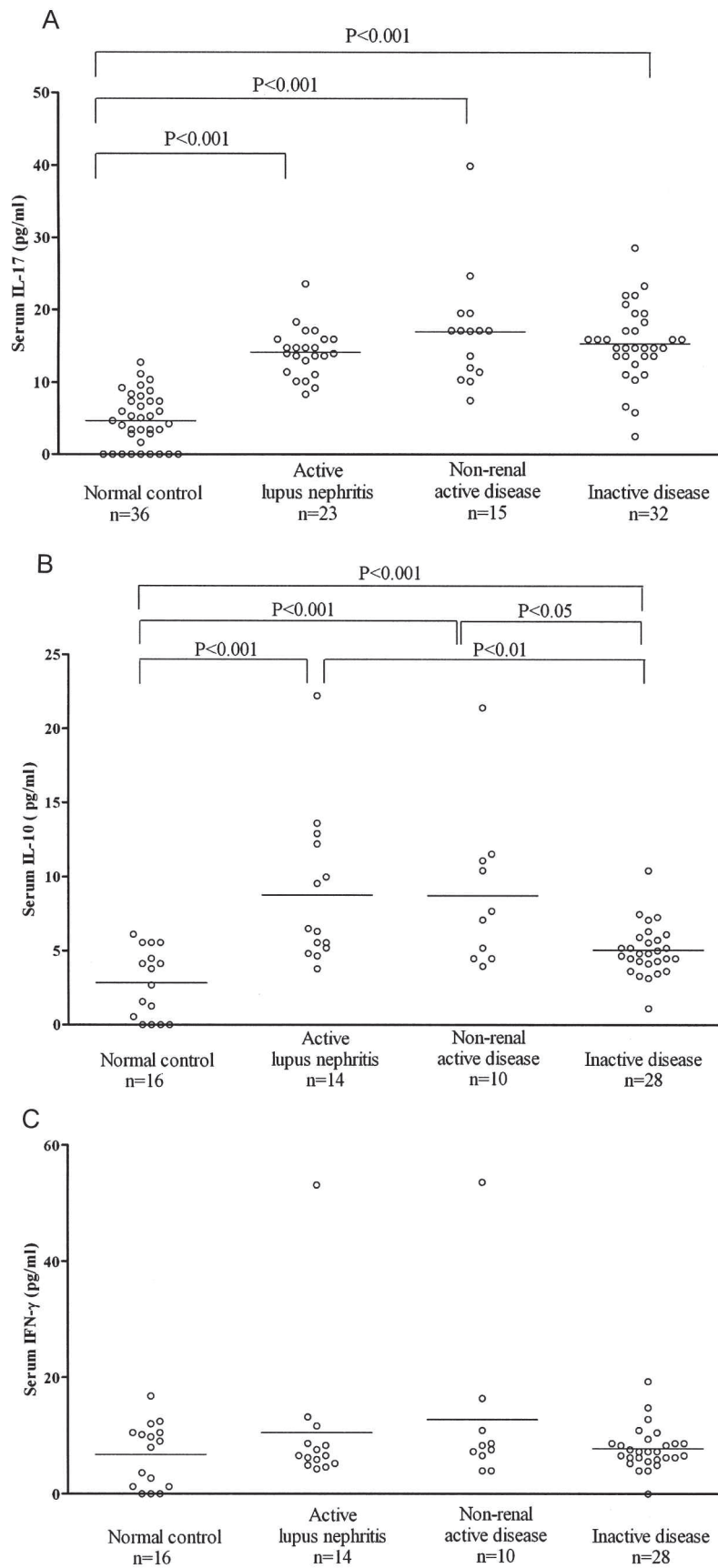


Figure 1. Serum levels of IL-17 (Figure 1A), IL-10 (Figure 1B) and IFN- γ (Figure 1C) in normal controls, patients with active lupus nephritis, non-renal active disease, and inactive disease.

= 0.59). Serum IL-17 levels were otherwise not found to be different between SLE patients who had impaired eGFR (15.4 vs 13.6 pg/ml, $p = 0.09$) and serum albumin < 35 g/l ($p = 0.36$) compared to those who did not have these features.

On the other hand, serum IL-10 was significantly higher in patients who had active lupus nephritis (6.4 pg/ml) ($p < 0.001$), non-renal active disease (7.4 pg/ml) ($p < 0.001$), and inactive disease (4.8 pg/ml) ($p < 0.001$) compared to controls (3.2 pg/ml) (Figure 1B). Patients who had active lupus nephritis were not different in their serum IL-10 levels from those who had systemic involvement ($p = 0.80$), but their levels were higher than those who had inactive disease ($p = 0.004$). Patients who had non-renal active lupus were also found to have higher IL-10 levels than patients with inactive disease ($p = 0.02$). Serum IFN- γ was not particularly different between patients who had active lupus nephritis (6.6 pg/ml), non-renal active disease (8.0 pg/ml), inactive disease (7.3 pg/ml), and healthy controls (8.5 pg/ml) ($p = 0.28$) (Figure 1C).

Correlation between serum levels of Th1, Th2, and Th17 cytokines. Among all patients with SLE, serum IL-17 levels were found to correlate only weakly with IL-4 levels ($r = 0.32$, $p = 0.02$). Serum IL-17 was not found to correlate with IL-10 ($p = 0.26$), IFN- γ ($p = 0.07$), IL-6 ($p = 0.21$), or IL-23 ($p = 0.15$). IL-23 was shown to correlate only weakly with serum levels of IL-4 ($r = 0.30$, $p = 0.03$). Serum levels of IL-6 were shown to correlate weakly with IL-10 ($r = 0.28$, $p = 0.045$).

Serum levels of Th1, Th2, and Th17 cytokines in relation to medications. Serum levels of IL-17 were not found to be related to use of prednisolone ($p = 0.96$), hydroxychloroquine ($p = 0.68$), or mycophenolate mofetil ($p = 0.06$). Patients who received concurrent azathioprine were found to have higher serum IL-17 levels than those not taking this medication (15.9 vs 13.6 pg/ml, $p = 0.01$). Serum IL-17 levels also showed a weak positive correlation with dosage of azathioprine ($r = 0.25$, $p = 0.04$). IL-23 and other cytokines were not found to be related to any of these medications.

DISCUSSION

Our study showed that patients with SLE had higher serum IL-17 levels than healthy subjects, in accordance with previous studies¹¹⁻¹³, suggesting a role of IL-17 in the pathogenesis of human lupus. We have further examined the relation of IL-17 and IL-23 with organ involvement, parameters of disease activity, and Th1/Th2 cytokines in our lupus patients. Our data showed that higher serum IL-23 levels were found in active SLE patients with cutaneous involvement and serositis compared to those without these features. Enhanced expression of IL-23 has previously been reported in lesional skin compared to non-lesional skin in patients with psoriasis and to normal skin²⁰. IL-23 and its related cytokines have also been shown to mediate systemic inflam-

mation including autoantibody production and cutaneous and renal manifestations in Ro52 knockout murine lupus model²¹. IL-23 has evolutionarily been involved in immune defense by rapid recruitment of neutrophils during acute infection⁶. This cytokine is released by antigen presenting cells within a few hours after exposure to lipopolysaccharide and other microbial products²². This leads to induction of IL-17, which promotes production of downstream proinflammatory cytokines including IL-1, IL-6, IL-8, and tumor necrosis factor- α by stromal cells, endothelial cells, and monocytes²³. Thus, dysregulation of the IL-17/IL-23 axis may lead to abnormal inflammatory response in SLE patients such as cutaneous involvement and serositis as demonstrated in our analysis. The acute IL-23 response is normally succeeded by Th1 response, which may account for the absence of association between serum IL-23 level and SLEDAI in our patients. IFN- γ has been suggested to promote expansion of Th17 cells through generation of an inflammatory milieu²⁴. It has also been shown to synergize with IL-17 in the mediation of IL-6 secretion²⁵, which constitutes a positive feedback loop for Th17 development²⁶. However, IL-10 and IL-6 instead of Th1 cytokines were found to be the predominant cytokines among our SLE patients compared to healthy subjects.

Elevated serum IL-17 levels were not found to be predominant over particular organ involvement in our SLE patients. Serum level of IL-17 was comparable between SLE patients with active disease and without inflammatory manifestations. We found increased serum IL-17 levels in patients with active lupus nephritis and non-renal active disease^{11,12}, as well as those who had inactive disease. Previous studies have demonstrated IL-17 producing T cells in kidney tissues from patients with lupus nephritis by immunohistochemistry^{27,28}. Serum IL-17 levels were not found to be related to eGFR, amount of proteinuria, activity or chronicity score, and ISN/RPS class of lupus nephritis among patients who had active renal disease; this suggests elevated IL-17 may not be solely related to renal involvement by lupus. Indeed, Th17 cells have also been found in peripheral blood, spleen, and other involved organs in addition to the kidneys in murine lupus models^{27,29,30}, consistent with our finding of elevated serum IL-17 in patients with non-renal active disease. Thus, it is likely that Th17 cells infiltrate into various organs with local production of IL-17 and induction of downstream proinflammatory cytokines perpetuating inflammation in the involved organs. CD4+ $\alpha\beta$ T cells, $\gamma\delta$ T cells and natural killer cells are sources of IL-17³¹. Both CD3+CD8- T cells and CD4-CD8- T cells were found to be the source of IL-17 in the circulation in human lupus^{27,28}. The elevated IL-17 levels found in patients with inactive disease may be attributed to subclinical disease in these patients. However, the cross-sectional design of our study limited our conclusion.

In regard to its relation with disease activity, higher

serum IL-17 levels and more abundant Th17 cells were reported in patients with active disease compared to those with lesser activity²⁷. Some studies showed direct correlation between serum IL-17 and SLEDAI³². However, our group and others¹¹ were not able to demonstrate such an association. Serum IL-17 was not related to parameters of disease activity including SLEDAI, serum levels of anti-dsDNA antibody, or C3 and C4 in our patients. We cannot exclude a possible influence of concurrent medications on cytokine levels. However, blood samples were collected from active patients prior to augmentation of immunosuppressive regimen. Patients receiving azathioprine were found to have higher serum IL-17 levels compared to patients not taking this medication. The positive relationship between azathioprine use and serum levels of IL-17 suggests that release of this cytokine is associated with more severe disease, further reinforcing a pathogenic role for IL-17 in SLE. Indeed, a recent study on newly diagnosed active SLE patients who were treatment-naïve demonstrated positive correlation between serum IL-17 level and SLEDAI¹⁴. On the other hand, our study revealed IL-10 as the only cytokine that was found to correlate strongly with these characteristics of disease activity in accordance with other studies^{33,34}. We did not find any significant correlation between serum IL-23/IL-17 levels and Th1/Th2 cytokines except for a weak correlation with IL-4. The lack of correlation between these cytokines suggests that the regulation of these cytokines is independent from each other. Further, the dynamic role of Th1, Th2, and Th17 cells may also evolve during different stages of disease as was suggested in a mouse model of autoimmune myasthenia gravis³⁵.

Other than IL-17, our lupus patients were found to have significantly higher serum levels of IL-6 and IL-10, both of which have been implicated in the pathogenesis of SLE. IL-6 is the most important B cell stimulating factor that induces differentiation of T cells into effector cells and has previously been shown to mediate tissue damage in lupus³⁵. We did not find correlation between IL-6 and lupus disease activity, but IL-6 was found to correlate weakly with IL-10 as reported in other studies³⁶. IL-10, produced by Th2 cells, has also been shown to regulate growth and differentiation of B lymphocytes and antibody production³⁷. On the other hand, IL-10 is produced by many other cell types including regulatory T cells and mediates inactivation of antigen presenting cells, inhibition of proinflammatory cytokine secretion, and expression of MHC class II and co-stimulatory molecules³⁸. In this study, we did not measure serum IL-22, the level of which has been reported to be diminished in SLE compared to controls^{12,39}. Both pro- and antiinflammatory properties of IL-22 have been described and its relation with lupus activity has been controversial^{12,39}.

In conclusion, our study demonstrated elevated serum IL-17 levels in patients with SLE compared to controls, supporting a role of IL-17 in the pathogenesis of SLE. Elevated

serum IL-17 was not found to be related to characteristics of disease activity but was present in both active lupus nephritis and non-renal active disease and perhaps patients with subclinical disease. On the other hand, serum IL-23 was found to be elevated in active lupus patients who presented with inflammatory manifestations including cutaneous involvement and serositis, further supporting a role of IL-23/Th17 in the pathogenesis of SLE. Our study was limited by small sample size, cross-sectional design and multiple statistical comparisons. Larger studies with longitudinal measurement of these cytokines may provide information in regard to their relationship with disease activity and clinical response to treatment in SLE patients. Indeed, therapeutic application of anti-IL-17 in collagen-induced arthritis mouse model has been shown to alleviate joint inflammation⁴⁰. Ustekinumab, a human interleukin-12/23 monoclonal antibody has also been shown to be efficacious in patients with moderate to severe skin psoriasis⁴¹.

REFERENCES

1. Steinman L. A brief history of T(H)17, the first major revision in the T(H)1/T(H)2 hypothesis of T cell-mediated tissue damage. *Nature Medicine* 2007;13:139-45.
2. Weaver CT, Hatton RD, Mangan PR, Harrington LE. IL-17 family cytokines and the expanding diversity of effector T cell lineages. *Ann Rev Immunol* 2007;25:821-52.
3. Ghilardi N, Ouyang W. Targeting the development and effector functions of TH17 cells. *Semin Immunol* 2007;19:383-93.
4. Ivanov II, McKenzie BS, Zhou L, Tadokoro CE, Lepelley A, Lafaille JJ, et al. The orphan nuclear receptor ROR γ directs the differentiation program of proinflammatory IL-17+ T helper cells. *Cell* 2006;126:1121-33.
5. McGeachy MJ, Bak-Jensen KS, Chen Y, Tato CM, Blumenschein W, McClanahan T, et al. TGF- β and IL-6 drive the production of IL-17 and IL-10 by T cells and restrain T(H)-17 cell-mediated pathology. *Nat Immunol* 2007;8:1390-7.
6. McKenzie BS, Kastelein RA, Cua DJ. Understanding the IL-23-IL-17 immune pathway. *Trends Immunol* 2006;27:17-23.
7. Chabaud M, Durand JM, Buchs N, Fossiez F, Page G, Frappart L, et al. Human interleukin-17: A T cell-derived proinflammatory cytokine produced by the rheumatoid synovium. *Arthritis Rheum* 1999;42:963-70.
8. Zaba LC, Fuentes-Duculan J, Eungdamrong NJ, Abello MV, Novitskaya I, Pierson KC, et al. Psoriasis is characterized by accumulation of immunostimulatory and Th1/Th17 cell-polarizing myeloid dendritic cells. *J Invest Dermatol* 2009;129:79-88.
9. Fujino S, Andoh A, Bamba S, Ogawa A, Hata K, Araki Y, et al. Increased expression of interleukin 17 in inflammatory bowel disease. *Gut* 2003;52:65-70.
10. Garrett-Sinha LA, John S, Gaffen SL. IL-17 and the Th17 lineage in systemic lupus erythematosus. *Curr Opin Rheumatol* 2008;20:519-25.
11. Zhao XF, Pan HF, Yuan H, Zhang WH, Li XP, Wang GH, et al. Increased serum interleukin 17 in patients with systemic lupus erythematosus. *Mol Biol Rep* 2009; Apr 4.
12. Cheng F, Guo Z, Xu H, Yan D, Li Q. Decreased plasma IL22 levels, but not increased IL17 and IL23 levels, correlate with disease activity in patients with systemic lupus erythematosus. *Ann Rheum Dis* 2009;68:604-6.
13. Wong CK, Lit LC, Tam LS, Li EK, Wong PT, Lam CW. Hyperproduction of IL-23 and IL-17 in patients with systemic

- lupus erythematosus: implications for Th17-mediated inflammation in auto-immunity. *Clin Immunol* 2008;127:385-93.
14. Chen XQ, Yu YC, Deng HH, Sun JZ, Dai Z, Wu YW, et al. Plasma IL-17A is increased in new-onset SLE patients and associated with disease activity. *J Clin Immunol* Jan 28.
 15. Hochberg MC. Updating the American College of Rheumatology revised criteria for the classification of systemic lupus erythematosus. *Arthritis Rheum* 1997;40:1725.
 16. Bombardier C, Gladman DD, Urowitz MB, Caron D, Chang CH. Derivation of the SLEDAI. A disease activity index for lupus patients. The Committee on Prognosis Studies in SLE. *Arthritis Rheum* 1992;35:630-40.
 17. Weening JJ, D'Agati VD, Schwartz MM, Seshan SV, Alpers CE, Appel GB, et al. The classification of glomerulonephritis in systemic lupus erythematosus revisited. *Kidney Int* 2004;65:521-30.
 18. Levey AS, Bosch JP, Lewis JB, Greene T, Rogers N, Roth D. A more accurate method to estimate glomerular filtration rate from serum creatinine: a new prediction equation. Modification of Diet in Renal Disease Study Group. *Ann Intern Med* 1999;16:130:461-70.
 19. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. *Am J Kidney Dis* 2002;39 Suppl 1:S1-266.
 20. Piskin G, Sylva-Steenland RM, Bos JD, Teunissen MB. In vitro and in situ expression of IL-23 by keratinocytes in healthy skin and psoriasis lesions: enhanced expression in psoriatic skin. *J Immunol* 2006;176:1908-15.
 21. Espinosa A, Dardalhon V, Brauner S, Ambrosi A, Higgs R, Quintana FJ, et al. Loss of the lupus autoantigen Ro52/Trim21 induces tissue inflammation and systemic autoimmunity by dysregulating the IL-23-Th17 pathway. *J Exp Med* 2009;3:206:1661-71.
 22. Smits HH, van Beelen AJ, Hessel C, Westland R, de Jong E, Soeteman E, et al. Commensal Gram-negative bacteria prime human dendritic cells for enhanced IL-23 and IL-27 expression and enhanced Th1 development. *Eur J Immunol* 2004;34:1371-80.
 23. Kolls JK, Linden A. Interleukin-17 family members and inflammation. *Immunity* 2004;21:467-76.
 24. Jandus C, Bioley G, Rivals JP, Dudler J, Speiser D, Romero P. Increased numbers of circulating polyfunctional Th17 memory cells in patients with seronegative spondylarthritides. *Arthritis Rheum* 2008;58:2307-17.
 25. Ruddy MJ, Wong GC, Liu XK, Yamamoto H, Kasayama S, Kirkwood KL, et al. Functional cooperation between interleukin-17 and tumor necrosis factor- α is mediated by CCAAT/enhancer-binding protein family members. *J Biol Chem* 2004;279:2559-67.
 26. Veldhoen M, Hocking RJ, Atkins CJ, Locksley RM, Stockinger B. TGF β in the context of an inflammatory cytokine milieu supports de novo differentiation of IL-17-producing T cells. *Immunity* 2006;24:179-89.
 27. Yang J, Chu Y, Yang X, Gao D, Zhu L, Yang X, et al. Th17 and natural Treg cell population dynamics in systemic lupus erythematosus. *Arthritis Rheum* 2009;60:1472-83.
 28. Crispin JC, Oukka M, Bayliss G, Cohen RA, Van Beek CA, Stillman IE, et al. Expanded double negative T cells in patients with systemic lupus erythematosus produce IL-17 and infiltrate the kidneys. *J Immunol* 2008;181:8761-6.
 29. Hsu HC, Yang P, Wang J, Wu Q, Myers R, Chen J, et al. Interleukin 17-producing T helper cells and interleukin 17 orchestrate autoreactive germinal center development in autoimmune BXD2 mice. *Nat Immunol* 2008;9:166-75.
 30. Kang HK, Liu M, Datta SK. Low-dose peptide tolerance therapy of lupus generates plasmacytoid dendritic cells that cause expansion of autoantigen-specific regulatory T cells and contraction of inflammatory Th17 cells. *J Immunol* 2007;178:7849-58.
 31. Roark CL, Simonian PL, Fontenot AP, Born WK, O'Brien RL. Gammadelta T cells: an important source of IL-17. *Curr Opin Immunol* 2008;20:353-7.
 32. Doreau A, Belot A, Bastid J, Riche B, Trescol-Biemont MC, Ranchin B, et al. Interleukin 17 acts in synergy with B cell-activating factor to influence B cell biology and the pathophysiology of systemic lupus erythematosus. *Nat Immunol* 2009;10:778-85.
 33. Houssiau FA, Lefebvre C, Vanden Berghe M, Lambert M, Devogelaer JP, Renauld JC. Serum interleukin 10 titers in systemic lupus erythematosus reflect disease activity. *Lupus* 1995;4:393-5.
 34. Park YB, Lee SK, Kim DS, Lee J, Lee CH, Song CH. Elevated interleukin-10 levels correlated with disease activity in systemic lupus erythematosus. *Clin Exp Rheumatol* 1998;16:283-8.
 35. Linker-Israeli M, Deans RJ, Wallace DJ, Prehn J, Ozeri-Chen T, Klinenberg JR. Elevated levels of endogenous IL-6 in systemic lupus erythematosus. A putative role in pathogenesis. *J Immunol* 1991;147:117-23.
 36. Mellor-Pita S, Citores MJ, Castejon R, Yebra-Bango M, Tutor-Ureta P, Rosado S, et al. Monocytes and T lymphocytes contribute to a predominance of interleukin 6 and interleukin 10 in systemic lupus erythematosus. *Cytometry* 2009;76B:261-70.
 37. Rousset F, Garcia E, Defrance T, Peronne C, Vezzio N, Hsu DH, et al. Interleukin 10 is a potent growth and differentiation factor for activated human B lymphocytes. *Proc Natl Acad Sci USA* 1992;89:1890-3.
 38. O'Garra A, Vieira P. T(H)1 cells control themselves by producing interleukin-10. *Nat Rev Immunol* 2007;7:425-8.
 39. Pan HF, Zhao XF, Yuan H, Zhang WH, Li XP, Wang GH, et al. Decreased serum IL-22 levels in patients with systemic lupus erythematosus. *Clin Chim Acta* 2009;401:179-80.
 40. Lubberts E, Koenders MI, Oppers-Walgreen B, van den Bersselaar L, Coenen-de Roo CJ, Joosten LA, et al. Treatment with a neutralizing anti-murine interleukin-17 antibody after the onset of collagen-induced arthritis reduces joint inflammation, cartilage destruction, and bone erosion. *Arthritis Rheum* 2004;50:650-9.
 41. Leonardi CL, Kimball AB, Papp KA, Yeilding N, Guzzo C, Wang Y, et al. Efficacy and safety of ustekinumab, a human interleukin-12/23 monoclonal antibody, in patients with psoriasis: 76-week results from a randomised, double-blind, placebo-controlled trial (PHOENIX 1). *Lancet* 2008;371:1665-74.