Soluble E-cadherin in Systemic Lupus Erythematosus
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ABSTRACT. Objective. E-cadherin is a potent adherens junction molecule implicated in tissue morphogenesis, epithelial function, and immune regulation. Serum levels of soluble E-cadherin (sE-cadherin), an end product of proteolytic cleavage of E-cadherin, is increased in patients with cancer, infections, and inflammation-related diseases. The aim of our study was to measure serum levels of sE-cadherin in systemic lupus erythematosus (SLE) and to determine associations between serum levels of sE-cadherin and markers of inflammation and organ damage in female patients with SLE.

Methods. Serum levels of sE-cadherin were analyzed by ELISA in 150 female patients with SLE and 31 healthy women. Simple and multiple regression analyses between sE-cadherin levels and disease-related variables were performed in patients with SLE.

Results. Serum levels of sE-cadherin were elevated in patients with SLE compared with levels in healthy controls. sE-cadherin levels correlated positively with age, disease duration, SLE Collaborating Clinics Damage Index, erythrocyte sedimentation rate (ESR), s-creatinine, cholesterol, triglycerides, interleukin 6, and matrix metalloproteinase-3. In multiple regression analysis, s-creatinine, age, ESR, and triglycerides remained determinants of sE-cadherin. Within the patients with SLE, higher sE-cadherin levels were found only in patients with renal damage, i.e., s-creatinine > 90 µmol/l, glomerular filtration rate < 50 ml/min, or renal involvement ever by SLE.

Conclusion. Our study demonstrates significantly elevated serum levels of sE-cadherin in women with SLE compared with healthy women. The levels of sE-cadherin were positively correlated to s-creatinine, age, ESR, and triglycerides. Significantly elevated sE-cadherin levels were observed only in patients with renal damage. (First Release Sept 1 2013; J Rheumatol 2013;40:1677–82; doi:10.3899/jrheum.130518)

Key Indexing Terms: sE-CADHERIN SYSTEMIC LUPUS ERYTHEMATOSUS RENAL DAMAGE

E-cadherin is a transmembrane glycoprotein highly expressed at the surface of epithelial cells, mediating calcium-dependent homotypic cell-cell adhesion. The cytoplasmic tail of E-cadherin forms a dynamic complex with catenins and regulates several intracellular signal transduction pathways. E-cadherin is responsible for joining adjacent epithelial cells and safeguarding epithelial barrier function.

Accumulating evidence suggests that E-cadherin also acts as an immunological regulator in addition to an adherens junction molecule. Langerhans cells are able to form a dense dendritic cell (DC) network with the highly E-cadherin-expressing keratinocytes to cover the entire body surface by using E-cadherin. Epidermal proinflammatory cytokines downregulate E-cadherin expression and attenuate E-cadherin mediated adhesion between those cells. Bone marrow-derived DC are also known to exhibit high amounts of surface E-cadherin. Loss of E-cadherin-mediated adhesion activates the β-catenin signaling pathway in DC, which protects against experimental allergic encephalomyelitis in mice. Indeed, ablation of β-catenin expression in DC enhanced inflammatory responses and inflammatory bowel disease in a mouse model. In contrast, monocyte-derived inflammatory DC that express E-cadherin promote intestinal inflammation. Besides its immune regulatory properties in DC, E-cadherin was identified as a marker for alternatively activated macrophages that were involved in homotypic and heterotypic interactions through interleukin (IL)-4 and E-cadherin/catenin complexes.

E-cadherin can be cleaved by several proteases such as matrix metalloproteinases (MMP), plasmin, kallikrein, and ADAM10. This process is called E-cadherin ectodomain shedding, which results in the release of an
80-kDa soluble peptide fragment referred to as soluble E-cadherin (sE-cadherin). Loss of E-cadherin mediated adhesions is a well-known characteristic when epithelial tumors progress toward malignancy. Indeed, sE-cadherin has been suggested as a diagnosis/prognosis biomarker for several forms of cancer, e.g., gastric cancer\textsuperscript{11,12}, bladder cancer\textsuperscript{13}, prostate cancer\textsuperscript{14}, ovarian cancer\textsuperscript{15}, colorectal cancer\textsuperscript{16}, melanoma\textsuperscript{17}, and lung cancer\textsuperscript{18}. Interestingly, sE-cadherin is upregulated not only in cancer, but also in different inflammatory conditions, e.g., sepsis\textsuperscript{19}, inflammatory skin diseases\textsuperscript{20}, pelvic inflammatory disease\textsuperscript{21}, and primary Sjögren syndrome\textsuperscript{22}. To the best of our knowledge, serum levels of sE-cadherin have not been investigated in SLE. We hypothesize that E-cadherin shedding may also happen in other inflammatory rheumatic diseases.

The aim of our study was to (1) assess serum levels of sE-cadherin in women with SLE and compare the levels with healthy controls; and (2) investigate associations between serum levels of sE-cadherin and disease-related variables in SLE.

**MATERIALS AND METHODS**

*Patients.* All patients with SLE attending rheumatology clinics during the winter and spring of 2002-2003 in Göteborg and Borås, in western Sweden, were invited to participate in this cross-sectional study, as described\textsuperscript{23}. The original aim of our study was to determine prevalence and risk factors of osteoporosis in women with SLE. One hundred fifty female patients fulfilling at least 4 of the 1982 American College of Rheumatology (ACR) classification criteria for SLE\textsuperscript{24} were included in and completed the study. The Systemic Lupus Erythematosus Disease Activity Index (SLEDAI-2K) was used to score disease activity\textsuperscript{25}. Disease damage was recorded according to the Systemic Lupus International Collaborative Clinics/ACR Damage Index (SLICC)\textsuperscript{26}. Glomerular filtration rate (GFR) was calculated using the Cockcroft and Gault equation\textsuperscript{27}:

\[
\text{GFR (ml/min)} = \frac{(140 - \text{age}) \times \text{weight (kg)} \times 1.04}{\text{S-creatinine (µmol/l)}}
\]

Cumulative corticosteroid intake was calculated by reading the medical records of all patients. The same rheumatologist (KA) examined all patients and reviewed all medical records. The clinical data and materials were further analyzed in the current study to investigate serum levels of sE-cadherin in those patients.

*Healthy controls.* A control group of 31 healthy female staff members and PhD students (age range 25–63 yrs) in the Department of Rheumatology were analyzed for serum levels of sE-cadherin, MMP-3, and MMP-9. No significant correlation was found between serum sE-cadherin and age.

*Laboratory tests.* Serum from venous blood samples and urine were collected, aliquoted, and stored at −70°C until the analyses of sE-cadherin, MMP-3, and MMP-9 following standard routines for handling, processing, and storage of biosamples. Erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), complete blood (cell) count, creatinine, and complement factors (C3 and C4), were analyzed consecutively in the Department of Clinical Chemistry of Sahlgrenska University Hospital. The Systemic Lupus Erythematosus Disease Activity Index (SLEDAI-2K) was used to score disease activity\textsuperscript{25}. Disease damage was recorded according to the Systemic Lupus International Collaborative Clinics/ACR Damage Index (SLICC)\textsuperscript{26}. Glomerular filtration rate (GFR) was calculated using the Cockcroft and Gault equation\textsuperscript{27}.

*sE-cadherin and cytokines.* The levels of sE-cadherin (in serum and urine), MMP-3, and MMP-9 in serum were determined using the specific sandwich ELISA kits (Quantikine; R&D Systems Inc.) according to the manufacturer’s protocols. The detection threshold was 0.09 ng/ml for sE-cadherin, 0.045 ng/ml for MMP-3, and 0.312 ng/ml for MMP-9. Quantitative sandwich ELISA kits were also used for measurement of proinflammatory cytokines tumor necrosis factor-α, IL-1β, IL-6, and soluble IL-6 receptor (sIL-6R; Quantikine; R&D Systems Inc.) with detection limits of 0.12, 0.1, 0.7, and 6.5 pg/ml, respectively.

*Ethical considerations.* All patients gave informed consent prior to participation, and the study was approved by the regional ethics committee at the University of Gothenburg.

*Statistical analysis.* Analyses were performed using PASW statistics 18 (SPSS Inc.). All variables were tested with the Kolmogorov-Smirnov normality test. Statistical comparisons of sE-cadherin levels in sera among patients with SLE and healthy controls were made using an unpaired t test when the variables followed a normal distribution, or sample size in each group was > 30. Mann-Whitney U test was used when the variable followed a non-normal distribution and sample size in 1 group was < 30. Pearson correlation was used when the variables were normally distributed; otherwise, Spearman correlation was used. Significant variables were then entered in the multiple linear regression analyses as independent variables and serum levels of sE-cadherin as the dependent variable. A forward stepwise method was used. All tests were 2-tailed, and a p < 0.05 was considered statistically significant.

**RESULTS**

*Demographic and disease-related variables.* The participants’ ages ranged from 20 to 82 years. Eighty-six (57%) were taking disease-modifying antirheumatic drugs (DMARD), and 79 (53%) were treated with glucocorticosteroids (mean dose of prednisolone 3.28 mg/day). Patients had the mean scores of 6.7 for SLEDAI and 2.9 for SLICC. The mean value of serum creatinine was 94.3 µmol/l. The calculated GFR was 73.2 ml/min on average. Only 1 person had endstage renal disease, but 9 (6.1%) had proteinuria over 3.5 g/24 h. Sixty-five patients (43.3%) had serum creatinine over 90 µmol/l, and 15 (10%) had a GFR of less than 50 ml/min by use of the calculated GFR value. More details of demographic and disease-related variables are in our previous publication\textsuperscript{28}, which used the same patient materials.

*Elevated serum levels of sE-cadherin in patients with SLE.* Table 1 shows the serum levels of sE-cadherin in 150 female patients with SLE and 31 healthy women. The patients with SLE did not differ significantly in age from the healthy controls (mean ± SD, 48.7 ± 12.7 vs 45.8 ± 11.3 years, respectively). sE-cadherin was elevated in patients with SLE as compared with healthy controls (93.3 ng/ml vs 80.6 ng/ml, p < 0.05).

**Correlations between serum levels of sE-cadherin and disease-related variables.** Associations between sE-cadherin and demographic and disease-related variables are found in Table 2. Significant correlations were observed
between sE-cadherin and patient age (r = 0.25, p < 0.01), disease duration (r = 0.24, p < 0.01), SLICC (r = 0.21, p < 0.01), ESR (r = 0.36, p < 0.0001), serum creatinine (r = 0.42, p < 0.0001), GFR (r = -0.53, p < 0.0001), cholesterol (r = 0.37, p < 0.0001), triglycerides (r = 0.36, p < 0.0001), IL-6 (r = 0.31, p < 0.0001), and MMP-3 (r = 0.31, p < 0.0001).

A multiple regression model was performed using sE-cadherin as the dependent variable and patient age, disease duration, SLICC, ESR, s-creatinine, GFR, cholesterol, triglycerides, IL-6, and MMP-3 as independent variables. S-creatinine, patient age, ESR, and triglycerides remained the most important determinants of serum levels of sE-cadherin levels ($R^2$ = 0.543; Table 3).

**Serum levels of MMP-3 in patients with SLE.** MMP have been found to be involved in the extracellular cleavage of E-cadherin. To study whether MMP-3 and MMP-9 is involved in E-cadherin shedding in SLE, the serum levels of MMP-3 were detected and associated with sE-cadherin. Increased levels of MMP-3 were found in patients with SLE compared to healthy controls (25.2 ± 23.4 ng/ml vs 10.2 ± 4.4 ng/ml, respectively, p < 0.01). Besides the significant association with sE-cadherin, MMP-3 is also significantly correlated with ESR (r = 0.21, p = 0.009), CRP (r = 0.26, p = 0.001), s-creatinine (r = 0.35, p < 0.0001), triglycerides (r = 0.21, p = 0.01), and IL-6 (r = 0.45, p < 0.0001). In contrast to MMP-3, MMP-9 was downregulated in patients with SLE compared with controls (288.6 ± 15.6 ng/ml vs 732.2 ± 66.1 ng/ml, respectively, p < 0.001). No significant correlation was found between MMP-9 and sE-cadherin in patients with SLE, suggesting that MMP-3 rather than MMP-9 might be involved in ectodomain shedding of E-cadherin.

**Increased serum levels of sE-cadherin in patients with SLE and renal damage.** To further investigate sE-cadherin in the context of renal damage, we divided patients with SLE into different subgroups (s-creatinine above 90 µmol/l or not, GFR above 50 ml/min or not, and SLE renal involvement ever or not; Figure 1). Significantly higher levels of sE-cadherin were found in patients with s-creatinine over 90 µmol/l than in ones with it below 90 µmol/l (p < 0.0001) and healthy controls (p < 0.001, Figure 1A). No difference was found between patients with s-creatinine below 90 µmol/l and healthy controls. Similar differences were also observed when patients were grouped according to GFR and ever having had nephritis (Figures 1B and 1C).

In contrast to serum sE-cadherin, urine sE-cadherin levels were not associated with s-creatinine levels in SLE. No significant difference in urine levels of sE-cadherin was found between the patients with s-creatinine over 90 µmol/l and ones below 90 µmol/l (20.4 ng/ml vs 17.1 ng/ml, respectively). sE-cadherin levels in urine were also similar in SLE subgroups divided according to GFR or renal involvement (data not shown). Intriguingly, significantly lower urine sE-cadherin levels were found in patients with 24-h urine protein ≥ 3.5 g than in patients with < 3.5 g (6.7 ng/ml vs 19.6 ng/ml, respectively, p < 0.05). However, only 6 patients had 24-h urine protein ≥ 3.5 g.

**DISCUSSION**

In our study, we demonstrated that serum levels of sE-cadherin were increased in female patients with SLE compared to healthy women. sE-cadherin correlated positively to creatinine, age, ESR, and triglycerides in patients with SLE.

The ligand to membrane-bound E-cadherin, αβ7/CD103, was found on human peripheral blood lymphocytes, and elevated αβ7/CD103 expression was associated with the presence of oral ulcers or serositis in patients with SLE. This finding suggests that increased...
αEβ7/CD103-E-cadherin interaction might contribute to epithelial inflammation, one of the most common manifestations of SLE. Elevated MMP by stimulation of cytokines and inflammatory mediators in autoimmune diseases are known to cleave membrane-bound E-cadherin and release the sE-cadherin. Therefore, we hypothesized that serum levels of sE-cadherin reflect the disease activity of SLE. The correlations between sE-cadherin and ESR and IL-6 suggest a potential relationship between sE-cadherin release and systemic inflammation in SLE. In accordance with these results, it has been shown that IL-1 causes shedding of E-cadherin from the cell surface of cultured human endothelial cells. In a mouse model, intratracheal antigen or lipopolysaccharide challenge induced focal sE-cadherin release that was correlated with infiltrated neutrophil numbers. Also, elevated serum levels of sE-cadherin have been found in patients with inflammation-related disease such as sepsis, inflammatory skin diseases, pelvic inflammatory disease, and primary Sjögren syndrome. However, we found no significant correlation between sE-cadherin levels and SLEDAI scores. The patients with high disease activity (SLEDAI > 10) in our study had a significantly higher dose of corticosteroid, which may have affected ESR and IL-6 (p < 0.001) compared with patients with SLEDAI 1–10. There was also a larger proportion of patients using DMARD, which might also influence the markers of inflammation, in this subgroup of the patients (p < 0.05). Additionally, our patient cohort consists of individuals with a large variability in SLE organ involvement. These aspects might contribute to the lack of association between sE-cadherin and SLEDAI.

In contrast to SLEDAI, high SLICC scores were found to be associated with higher levels of sE-cadherin in patients with SLE. Renal damage is one of the most important domains in SLICC. Indeed, higher serum levels of sE-cadherin were found only in patients with elevated s-creatinine, low GFR, and kidney involvement ever by SLE, suggesting a direct association between sE-cadherin levels and renal damage in patients with SLE. One can speculate that elevated sE-cadherin in blood might be the consequence of an accumulating effect due to low GFR, because significantly lower urine sE-cadherin levels were found in patients with 24-h urine protein > 3.5 g compared to patients with 24-h urine protein < 3.5 g. However, that factor does not seem to be the whole explanation, because no significant correlation was found between urine sE-cadherin and serum sE-cadherin. Our question remains: does E-cadherin shedding happen locally in kidneys during renal damage in SLE? In kidneys, E-cadherin is dominantly expressed in tubule epithelia cells, especially in distal and collecting tubules. Glomeruli are the target structure of acute inflammation in lupus nephritis, while tubulointerstitial infiltration of inflammatory cells appears frequently and is considered a good indicator of renal function and prognosis. In the last decade, the epithelial-to-mesenchymal transition (EMT) of tubule cells has been identified as another significant mechanism, which contributes to progression of tubulointerstitial fibrosis and chronic kidney disease. Importantly, loss of E-cadherin expression is considered a hallmark of EMT. It has been shown that disruption of E-cadherin by MMP directly mediates renal tubular cell EMT and consequently leads to kidney fibrosis. In our study, the relationship between elevated serum levels of MMP-3 and sE-cadherin suggests that MMP-3 might be one of the potent enzyme resources for E-cadherin shedding in SLE. Indeed, serum levels of MMP-3 have been shown to be increased in patients with active lupus nephritis. Thus, our findings suggest a possible connection between MMP-3, sE-cadherin, and renal pathology in SLE nephritis. However, circulating sE-cadherin levels do not necessarily reflect the local E-cadherin expression in kidneys, as transforming growth factor-β1 (an important inducer for E-cadherin shedding) does in SLE. To elucidate the role of E-cadherin shedding in SLE nephritis, we need to further study the expression of E-cadherin and its regulatory factors in kidneys of patients.
with active lupus nephritis and those with chronic renal damage.

Patients with SLE have a high risk of cardiovascular diseases (CVD), which connected to the dyslipoproteinemia with high triglycerides (TG)/low high-density lipoprotein in SLE, correlated with disease activity. CVD has become a major cause of mortality in patients with SLE. Interestingly, the death rate among patients with SLE has drastically declined in the past decades, probably as a result of better and earlier treatment, while the risk of cardiovascular death remains unchanged. In our study, besides creatinine, ESR, and age of the patients, TG were positively connected with sE-cadherin. It has been shown before that serum levels of sE-cadherin positively correlate to the age of the patients with gastric cancer. However, the correlation between TG and sE-cadherin was, to our best knowledge, not known before, and it persisted in the multiple regression model. The mechanism for how E-cadherin shedding connects to lipid metabolism in SLE and the clinical significance of this result need to be further investigated.

The clinical implications of our findings are that sE-cadherin was only increased in the patients with pathologically elevated creatinine and low GFR. In the patients with SLE whose kidneys are affected, the sE-cadherin levels were also significantly increased compared with other patients with SLE and healthy controls. The strong correlation between TG and sE-cadherin suggests that sE-cadherin might be an indicator for cardiovascular risk/damage in SLE. All together, increased sE-cadherin levels seem to relate to several domains of disease damage in SLE.

We found elevated serum levels of sE-cadherin in patients with SLE compared with healthy individuals. sE-cadherin was associated with age, TG, s-creatinine, and ESR. To our knowledge, our results showed for the first time a possible relationship between lipid metabolism and E-cadherin shedding in patients with SLE. Importantly, elevated levels of sE-cadherin were only found in patients with SLE and severe renal damage. Our study suggests that sE-cadherin may be used as a biomarker for kidney damage in patients with SLE.

REFERENCES


