

## INVESTIGATIVE REPORT

# Cutaneous T-cell Lymphoma and Pruritus: The Expression of IL-31 and its Receptors in the Skin

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**Approximately 88% of cutaneous T-cell lymphoma (CTCL) patients are affected by pruritus that responds poorly to current antipruritic therapies. Interleukin (IL)-31, a Th2 cytokine, has been found to be increased in the serum of CTCL patients and to correlate with itch severity. This study investigated the role of IL-31 and its receptors (IL-31 receptor-alpha [IL-31RA] and OSMR $\beta$ ) in the skin of CTCL patients with mild versus moderate/severe pruritus. Expression levels of IL-31, IL-31RA, and OSMR $\beta$  in the skin were measured using immunohistochemistry and correlated to pruritus severity and disease stage. In CTCL patients with moderate/severe pruritus, IL-31 was significantly elevated in the epidermis and dermal infiltrate, while IL-31RA and OSMR $\beta$  were significantly elevated only in the epidermis. Furthermore, epidermal IL-31 levels correlated to itch severity. These results show that IL-31 may play a role in CTCL pruritus by exerting indirect effects on sensory nerves through epidermal neoplastic T cells and keratinocytes to transmit itch. *Key words:* CTCL; skin; pruritus; IL-31; IL-31RA; OSMR $\beta$ .**

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Pruritus significantly impacts the lives of patients with cutaneous T-cell lymphoma (CTCL), the most common forms of which are mycosis fungoides (MF) and Sézary syndrome (SS) (1–6). Surveys of patients with CTCL have found a prevalence of pruritus between 66% and 88% (1–3). Because pruritus of CTCL is non-histaminergic, it is difficult to treat and responds poorly to antihistamines (4, 6). The need for a more complete understanding of the pathophysiology of CTCL pruritus has led to an investigation into potential pruritic mediators.

Cytokines may play an important role in the pruritus of CTCL. CTCL skin lesions typically express Th2 cy-

tokines, such as interleukins (IL)-4, 5, 6, 9, 10, and 13. Th2 expression increases as the disease progresses, which may explain why pruritus can be more severe at later stages of the disease (6, 7). Studies in other pruritic disorders have found elevated levels of IL-31, a member of the IL-6 family of cytokines, in atopic dermatitis, prurigo nodularis, and allergic contact dermatitis (8–11). IL-31 acts through a heterodimeric receptor composed of IL-31 receptor alpha (IL-31RA) and oncostatin M receptor beta (OSMR $\beta$ ) (12). IL-31 is produced by a variety of sources, including Th2 T-cells, dendritic cells, mast cells, and keratinocytes. IL-31RA and OSMR $\beta$  are expressed on keratinocytes and dorsal root ganglia, which conduct the afferent sensation of pruritus (12).

Recently, Singer et al. (13) found that the malignant T-cell population produced IL-31 and that the increased levels of this cytokine in serum and peripheral blood mononuclear cells correlated with pruritus severity. In another study, IL-31 serum levels were elevated in CTCL patients but did not correlate with pruritus severity (14). However, these observed differences could be due to differences in the patients' stages of CTCL. Given the potential association between IL-31 and pruritus, we investigated the expression of IL-31 and its receptors in patients with CTCL and correlated our findings with both the clinical stage of each patient and the severity of their pruritus.

We discovered that expression levels of IL-31, IL-31RA, and OSMR $\beta$  were elevated in the epidermis of affected CTCL skin and that IL-31 expression was significantly correlated with itch severity. These results offer insight into the pathophysiology of pruritus in CTCL.

## METHODS

### *Subjects*

Skin biopsies were obtained from CTCL patients and healthy subjects at the dermatology clinics of Temple University, Northwestern University, and the University of Pennsylvania in accordance with the Declaration of Helsinki and with approval by each institution's Institutional Review Board.

Patients were diagnosed based on clinical, histopathological, and immunohistological criteria and staged using the Tumor-Node-Metastasis-Blood (TNMB) 2007 International Society for Cutaneous Lymphomas (ISCL) and European Organization of Research and Treatment of Cancer (EORTC) revised classifica-

tion system (15, 16). Patient characteristics are described in Table I. Patients with MF had patch lesions biopsied for stage IB and plaque lesions biopsied for stage IIB. Tumor lesions were biopsied for patients with stage IIB folliculotropic MF. SS patients had patch lesion biopsies performed and the patient with primary cutaneous  $\gamma\delta$  T-cell lymphoma was biopsied in a plaque lesion.

Pruritus severity was measured at the time of the biopsy using a visual analog scale (VAS). Subjects were grouped into the following categories: mildly pruritic CTCL (VAS 1–5;  $n=8$ ), moderately/severely pruritic CTCL (VAS 6–10;  $n=15$ ), and healthy controls (VAS 0;  $n=8$ ). We did not recruit CTCL patients without pruritus.

*Histology and immunohistochemistry*

Researchers were blinded to the identity of the biopsies and the results were only decoded after the analysis was fully performed. For histology to confirm disease stage, 5- $\mu$ m thick sections of paraffin-embedded skin tissue were processed for standard hematoxylin and eosin (H&E) staining.

For immunohistochemistry, a total of 12 20- $\mu$ m thick sections of paraffin-embedded skin tissue were double stained from each biopsy. Sections were deparaffinized and then underwent antigen retrieval using Target Retrieval Solutions (DAKO, Glostrup, Denmark) heated in a humidified oven overnight at 60°C, then washed in PBS. Sections were blocked with 5% normal donkey serum and 0.2% Triton X-100 in PBS for 2 h and then incubated with primary antibodies overnight at 4°C. Primary antibody combinations were: anti-PGP9.5 (1:50; Abcam, Cambridge, MA) and anti-IL-31 (1:100; Abcam); anti-IL-31RA (1:200, Abcam) and anti-OSMR $\beta$  (1:100; Santa Cruz, Dallas, Texas). Alexa Fluor (488 & 594, 1:300; Molecular Probes, Eugene, OR) secondary antibodies were used for detection. The slides were mounted with Vectashield with DAPI (Vector Laboratories, Burlingame, CA) and imaged under a fluorescence microscope.

Sections treated without any primary antibodies were used as negative controls. Furthermore, specificity of the IL-31 and IL-31RA antibody was confirmed by pre-absorbing the full length IL-31 and IL-31RA peptides (20  $\mu$ g/ml; Abcam) in blocking solutions with their respective antibodies overnight at 4°C with gentle agitation. Solutions were centrifuged, and the supernatant was used for IHC as described above, which resulted in blocking the IL-31 and IL-31RA immunoreactivity.

*Quantification*

Three fields (20X objective magnification) were measured for every section. The total field and selected field (epidermis)

Table I. Sample demographic data

	Moderately/severely pruritic CTCL $n=15$	Mildly pruritic CTCL $n=8$	Healthy controls $n=8$
Age, years, mean $\pm$ SD	65 $\pm$ 13.9	69.4 $\pm$ 12.6	66.9 $\pm$ 9.7
Sex (M:F), $n$	7:8	4:4	4:4
VAS rating, mean $\pm$ SD	7.5 $\pm$ 1.2	2.5 $\pm$ 1.5	0
Diagnosis, $n$			
Mycosis fungoides (MF)	3 (IB) <sup>a</sup> , 1 (IIB)	1 (IB)	
Folliculotropic MF	3 (IIB)	2 (IIB)	
Sézary syndrome	7 (IVA)	5 (IVA)	
PCGDTCL	1 (T3N2M0)	0	

<sup>a</sup>Stage (Tumor-Node-Metastasis-Blood).

PCGDTCL: primary cutaneous gamma delta T-cell lymphoma.

fluorescence area (in  $\mu$ m<sup>2</sup>) were measured and normalized to background staining using ImageJ Software. Data is presented as the mean epidermal fluorescence and mean dermal infiltrate fluorescence, which was calculated as the total field – selected field fluorescence. Inter-epidermal nerve fibers were counted and normalized to tissue length as previously described (17). The immunofluorescence staining was further compared to the H&E staining to examine localization of positive staining to lymphocytes.

Statistical analysis was carried out using one-way ANOVAs with Bonferroni *post hoc* tests and non-parametric two-tailed Spearman correlations with linear regression; significance was set at  $p < 0.05$  (GraphPad Prism; La Jolla, CA).

RESULTS

*Cutaneous T-cell lymphoma characteristics and pruritus*

The mean ages of the 3 groups (Table I) did not significantly differ from one another. There was a statistically significant difference ( $p < 0.0001$ ) in pruritus VAS ratings among healthy (VAS 0), mildly pruritic CTCL (VAS 2.5  $\pm$  1.5), and moderately/severely pruritic CTCL (VAS 7.5  $\pm$  1.2) subjects (Fig. 1A). No correlation was found between age and VAS ratings (Fig. 1B). The stage of CTCL correlated to VAS ratings ( $r=0.85$ ,  $p=0.04$ ) in mildly pruritic CTCL subjects only (Fig. 1C).

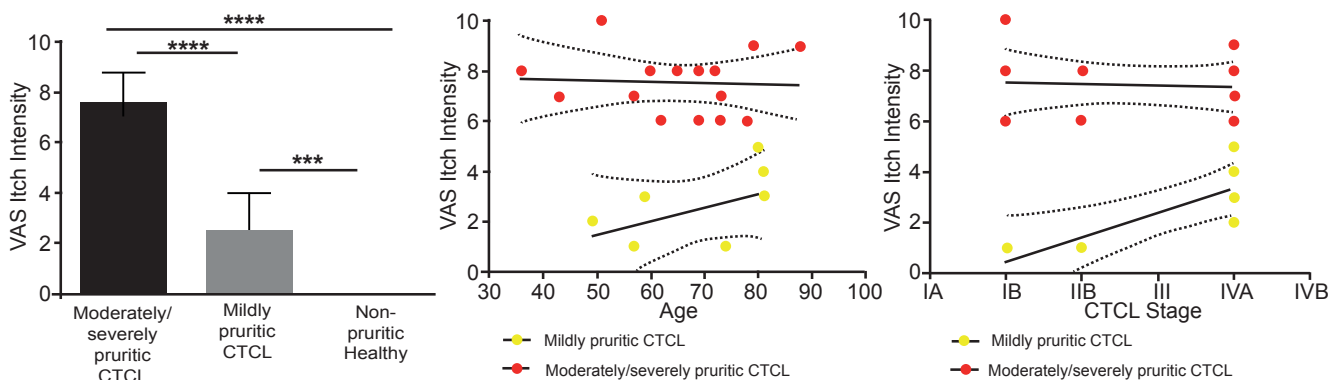


Fig. 1. Pruritic VAS rating and its correlation to cutaneous T-cell lymphoma (CTCL) stage. (A) The pruritic VAS rating was significantly higher in CTCL patients when compared to healthy controls (\*\* $p < 0.001$ , \*\*\*\* $p < 0.0001$ ). (B) The pruritus rating did not correlate to subject age. (C) The pruritus ratings correlated to CTCL disease stage in the mildly pruritic CTCL group only.

*IL-31 and epidermal innervation (PGP 9.5)*

IL-31 was significantly ( $p < 0.0001$ ) increased in the epidermis and lymphocytic infiltrate of CTCL subjects, with the moderately/severely pruritic CTCL subjects having the highest levels of IL-31 in the skin (Fig. 2A). The mean  $\pm$  SD IL-31 fluorescence levels in the epidermis of moderately/severely pruritic CTCL subjects were  $1,859 \pm 271$ , while the infiltrate levels were  $1,049 \pm 164$ . In mildly pruritic CTCL subjects, the IL-31 levels were  $1,489 \pm 123$  in the epidermis and  $625 \pm 123$  in the infiltrate. Healthy controls did present with some constitutive IL-31 in the epidermis, with levels of  $239 \pm 72$ , but little to none in the dermis ( $5 \pm 15$ ). Interestingly, in all subjects, IL-31 expression was limited to the lymphocytic infiltrate in the dermis and in the epidermis (representative image: Fig. 2B). No significant difference among groups was found in the number of epidermal nerve fibers, and IL-31 did not appear to co-localize to any afferent fibers (data not shown). Epidermal IL-31 levels significantly correlated ( $r = 0.94$ ;  $p < 0.0001$ ) with VAS ratings (Fig. 2C), but not with CTCL stage ( $r = 0.04$ ;  $p = 0.86$ ; Fig. 2D).

*IL-31RA and OSMR $\beta$*

IL-31RA was significantly ( $p < 0.0001$ ) elevated in only the epidermis of CTCL subjects (Fig. 3A; representative image: Fig. 3C). The mean  $\pm$  SD IL-31RA fluorescence levels were highest in moderately/severely pruritic subjects, with levels of  $1,394 \pm 183$  in the epidermis and  $50 \pm 12$  in the lymphocytic infiltrate. Mildly pruritic CTCL subjects had expression levels of  $620 \pm 42$  in the

epidermis and  $21 \pm 29$  in the infiltrate, while healthy controls had levels of only  $377 \pm 56$  in the epidermis and  $12 \pm 3$  in the dermis. Epidermal IL-31RA levels significantly correlated ( $r = 0.84$ ;  $p < 0.0001$ ) with VAS ratings (Fig. 3B), but not with CTCL stage ( $r = -0.01$ ;  $p = 0.96$ ).

Furthermore, OSMR $\beta$  was also significantly ( $p < 0.0001$ ) higher in the epidermis of CTCL subjects (Fig. 3D); representative image: Fig. 3F). In moderately/severely pruritic CTCL subjects, the mean  $\pm$  SD OSMR $\beta$  fluorescence levels were  $693 \pm 184$  in the epidermis and  $142 \pm 93$  in the lymphatic infiltrate. Mildly pruritic CTCL subjects had levels of  $421 \pm 83$  in epidermis and  $174 \pm 123$  in the lymphocytic infiltrate. The lowest levels of OSMR $\beta$  were observed in healthy controls (epidermis  $183 \pm 26$ ; dermis  $78 \pm 15$ ). Epidermal OSMR $\beta$  levels significantly correlated ( $r = 0.85$ ;  $p < 0.0001$ ) with VAS ratings (Fig. 3E), but not with CTCL stage ( $r = -0.16$ ;  $p = 0.47$ ).

DISCUSSION

Although several recent studies have found increased levels of IL-31 in CTCL, these studies largely focus on serum analysis and do not address the crucial question of IL-31's role in the skin (13, 14, 18). This is the first study to show the expression levels and patterns of IL-31 and both of its receptors within the skin of CTCL subjects with pruritus. Similar to most of the previous serum studies, this study shows that elevated IL-31 is positively correlated to itch intensity (13, 18). We also report that IL-31 was not correlated to disease stage, suggesting that IL-31 does not play an essential

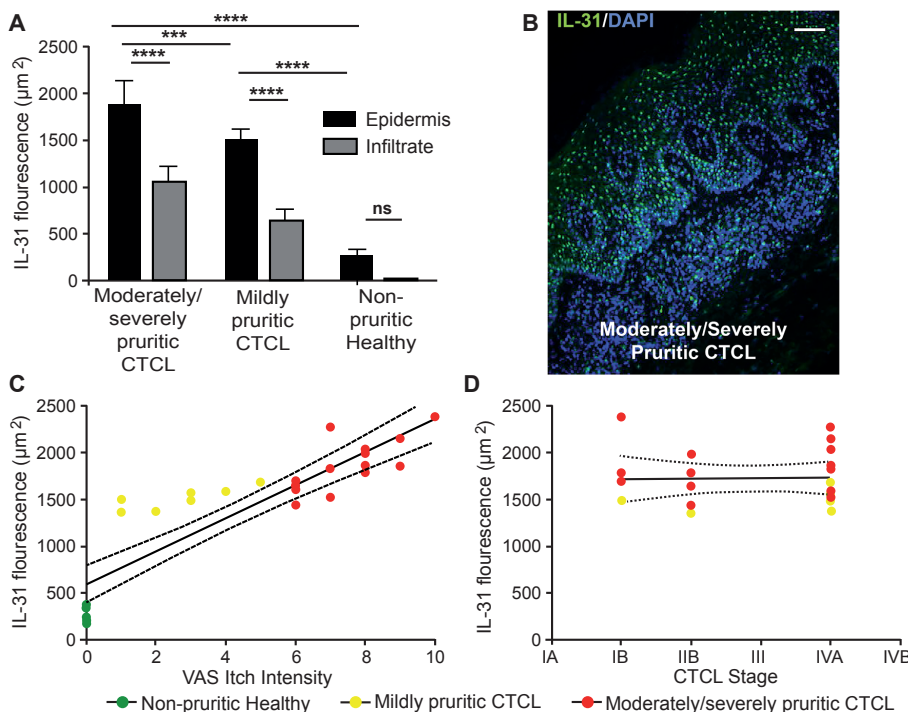


Fig. 2. IL-31 is increased in patients with pruritic cutaneous T-cell lymphoma (CTCL). (A) IL-31 was elevated in the epidermis and lymphocytic infiltrate of CTCL patients ( $***p < 0.001$ ,  $****p < 0.0001$ ), with the highest expression in the epidermis of the moderately/severely pruritic CTCL group (B). Scale bar = 100  $\mu\text{m}$ . (C) Epidermal IL-31 expression correlated to pruritic VAS ratings, but not with CTCL stage (D). DAPI: Blue staining of nuclei.

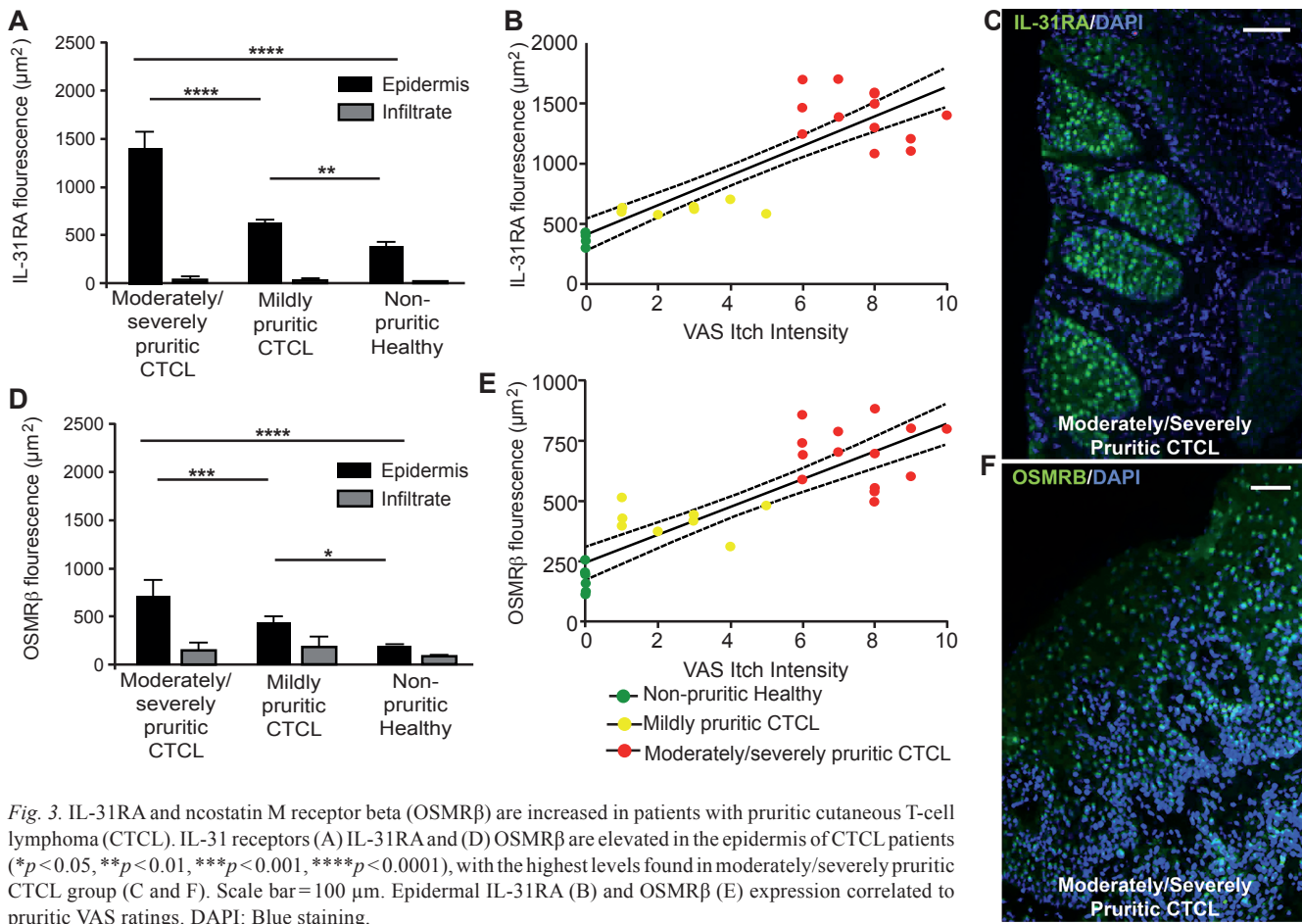


Fig. 3. IL-31RA and ncostatin M receptor beta (OSMR $\beta$ ) are increased in patients with pruritic cutaneous T-cell lymphoma (CTCL). IL-31 receptors (A) IL-31RA and (D) OSMR $\beta$  are elevated in the epidermis of CTCL patients ( $*p < 0.05$ ,  $**p < 0.01$ ,  $***p < 0.001$ ,  $****p < 0.0001$ ), with the highest levels found in moderately/severely pruritic CTCL group (C and F). Scale bar = 100  $\mu\text{m}$ . Epidermal IL-31RA (B) and OSMR $\beta$  (E) expression correlated to pruritic VAS ratings. DAPI: Blue staining.

role in the pathogenesis of CTCL. However, our study was limited by the low number of early stage CTCL patients and by the lack of CTCL patients without itch.

This study also found increased expression of the IL-31 receptors, IL-31RA and OSMR $\beta$ . The previous findings for these receptors in CTCL is limited to one serum and cancer cell line study, which did not find evidence of significant elevation of these receptors, possibly due to their focus on the blood compartment of CTCL cells (18). The IL-31RA and OSMR $\beta$  receptors are known to be located on keratinocytes, rather than serum, making this study better suited to assess the role of IL-31 signaling in CTCL. Interestingly, a recent study in mice showed that repeated IL-31 exposure caused elevated expression of IL-31RA and OSMR $\beta$  in the dorsal root ganglia (19). This mechanism could explain the increase in receptor density we found in the epidermis. In another study, a single intradermal exposure of IL-31 did not cause pruritus in healthy subjects (20). Therefore, the increase in IL-31RA and OSMR $\beta$  expression after chronic exposure to IL-31 may be necessary in order for a subsequent exposure to IL-31 to induce pruritus.

Our study showed elevated expression of IL-31 in the epidermis. This result is similar to studies performed

in atopic dermatitis subjects, which localized IL-31 to lymphocytes infiltrating the skin (11), and in lichen planus, which found overexpression of IL-31 in the epidermis. However, IL-31 expression in lichen planus did not correlate to pruritus ratings (21). It is thought that IL-31 can induce keratinocytes and infiltrating cells to release additional mediators involved in pruritus. Furthermore, IL-31 has also been shown to cause the release of pro-inflammatory cytokines from eosinophils, monocytes, and macrophages (22, 23). It would be of great interest to investigate the role of other pruritic mediators and cell types involved in CTCL pruritus.

The finding of elevated IL-31 and its receptors in the skin of pruritic CTCL subjects adds the missing link to previous studies investigating the role of IL-31 in CTCL pruritus. As pruritus treatments begin to focus on reducing IL-31 in CTCL patients, it will be interesting to correlate the therapeutic response with epidermal IL-31, as well as possible changes in the expression of IL-31 receptors (13, 24, 25).

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The authors declare no conflict of interest.

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