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Expression of interleukin-33 is correlated with poor prognosis of patients with squamous cell carcinoma of the tongue

Kazuya Ishikawa, Sayaka Yagi-Nakanishi, Yosuke Nakanishi, Satoru Kondo, Akira Tsuji, Kazuhira Endo, Naohiro Wakisaka, Shigeyuki Murono, Tomokazu Yoshizaki *

Division of Otolaryngology, and Head & Neck Surgery, Graduate School of Medical Science, Kanazawa University, Takara-machi 13-1, Kanazawa, Ishikawa 920-8640, Japan

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ABSTRACT

Objective: The aim of this study was to clarify the role of IL-33 in tumor progression.
Methods: Surgical specimens from 81 patients with squamous cell carcinoma of the tongue were studied using immunohistochemistry. Primary tumor sections were analyzed for IL-33 and ST2 expression. To examine the influence of IL-33 on the microenvironment of the tumor, we determined the mast cell density (MCD) and microvessel density of the stroma.
Results: Patients with high IL-33 expression had a significantly worse prognosis ($p = 0.004$). IL-33 expression was significantly elevated in patients with local and nodal recurrence ($p = 0.014$ and $p = 0.019$). ST2 expression was also associated with a worse prognosis ($p = 0.024$) and was significantly elevated in patients with nodal recurrence ($p = 0.004$). MCD was associated with worse prognosis ($p = 0.038$) and correlated significantly with IL-33 expression ($r = 0.626$, $p < 0.001$). Micovessels in the stroma were significantly increased in the high IL-33 group ($p < 0.001$).
Conclusion: These data suggest that the IL-33/ST2 axis contributes to tumor aggressiveness and affects the tumor microenvironment. Immunohistochemical evaluation of IL-33 and ST2 is useful for identifying patients at a high risk for poor prognosis.

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1. Introduction

Tongue squamous cell carcinoma (SCC) is one of the most common head and neck cancers. Prognosis is associated with clinical stage, particularly nodal status. Therefore, the expression of metastasis-related factors such as matrix metalloproteinases, syndecans, and vascular endothelial growth factor predicts the treatment outcome of patients with tongue SCC [1–4]. Tongue SCC is associated with inflammation in the oral cavity, which is mediated by chronic trauma such as smoking, alcohol consumption, and periodontal disease and is associated with oral carcinogenesis [5]. Moreover, inflammation promotes cancer development and progression through its effects on the tumor microenvironment [6]. Inflammatory mediators and specific cell types influence the migration, invasion, and metastasis of tumor cells [6]. Therefore, efficacious therapies must be developed for targeting inflammation in patients with cancer.

Interleukin (IL)-33 is a member of the IL-1 family and functions as a ligand for ST2, which is a member of the IL-1 receptor family. IL-33 is expressed by many cell types, including epithelial cells, endothelial cells, smooth muscle cells, fibroblasts, and activated macrophages [7]. In contrast, mast cells (MCs), Th2 cells, eosinophils, basophils, epithelial cells, and endothelial cells express ST2 [8–12]. Unlike other members of the IL-1 family, the cleavage site for caspases is located within the IL-1-like domain of IL-33, and the cleavage products are biologically inactive.

Biologically active, full-length IL-33 is released when cells sense inflammatory signals or undergo necrosis. Therefore, IL-33 acts as an endogenous danger signal or "alarmin" [8,13,14]. Binding of extracellular IL-33 to ST2 preferentially induces Th2-type immune responses with concomitant expression of Th2-associated cytokines [7]. It is clear that the potency of IL-33 for activating several immunocytes probably impacts inflammation. For example, IL-33 is expressed by patients with chronic gastritis, chronic hepatitis, and inflammatory bowel disease [15–17]. Inflammatory diseases increase the risk of developing cancer, suggesting that IL-33 may play an important role in cancer pathogenesis [18,19].

* Corresponding author at: Division of Otolaryngology, and Head & Neck Surgery, Graduate School of Medical Science, Kanazawa University, Takara-machi 13-1, Kanazawa, Ishikawa 920-8640, Japan. Tel.: +81 76 265 2413; fax: +81 76 234 4265.
E-mail address: tomoy@med.kanazawa-u.ac.jp (T. Yoshizaki).

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IL-33 affects the phenotype of cell types that express the transmembrane isoform of ST2. The inflammatory component of a neoplasm may include a diverse leukocyte population, and ST2 is expressed on many of these inflammatory cells, including MCs, macrophages, dendritic cells, eosinophils, and neutrophils [8,20]. Among the inflammatory cells in the stroma of the tumor, MCs are important because they secrete cytokines and chemokines, and influence the phenotypes of other cells through these soluble mediators as well as through cell–cell interaction. Moreover, MCs reside in the connective tissue surrounding tumors, and the accumulation of MCs is often associated with poor prognosis [21,22]. IL-33 is a potent activator of MCs and induces their degranulation and maturation, promotes survival, and induces the production of several proinflammatory cytokines [9,23]. Therefore, it is reasonable to assume that IL-33 contributes significantly to the malignant potential of tumor cells through the formation of an inflammatory tumor microenvironment.

We reported the carcinogenic role of activation-induced cytidine deaminase (AID), which is induced by an inflammatory environment [24]. However, the expression of AID does not correlate with the progression of tongue SCC, which diverted our attention to IL-33. Inflammation mediated by tobacco smoking, which is associated with tongue SCC, induces the expression of IL-33/ST2 in mice [25]. In the present study, we determined the expression of IL-33 in patients with tongue SCC using immunohistochemistry and assessed the relationship between the expression of IL-33 and prognosis of tongue SCC. Furthermore, to evaluate the influence of IL-33 on the tumor microenvironment, we determined the density of MCs in the stroma surrounding the tumor.

2. Materials and methods

2.1. Patients and specimens

This study included 81 patients who were diagnosed with tongue SCC. Informed consent was obtained from all patients in accordance with our institutional guidelines. The patient characteristics are presented in Table 1. Their clinical status was determined according to the TNM classification system of the Union Internationale Contre le Cancer [26]. All patients underwent surgery at the Division of Otolaryngology-Head and Neck Surgery, Kanazawa University Hospital between 1982 and 2007. Resection of the primary tongue tumor was performed in all patients, and neck dissection was performed in 53 patients with clinically positive nodes or tumors that were more advanced than stage T2. The 22 patients with positive margins or pathologically positive lymph node metastasis underwent postoperative treatment, including radiotherapy. The mean follow-up period was 50.7 months (median, 41 months; range, 1–131 months). Disease-free survival was calculated from the date of treatment until the time of local recurrence or the detection of metastases, including recurrence in the neck lymph nodes.

2.2. Immunohistochemical analysis

All specimens were the primary tumors. They were fixed in 10% formalin solution and embedded in paraffin. Serial 3-μm-thick sections were cut from each block, dewaxed, and rehydrated. Antigen retrieval was performed by heating slides for 30 min in citrate buffer (pH 6.0) at 90 °C, cooling for 20 min, and washing. Endogenous peroxidase was quenched with methanol and 3% H_2O_2 for 10 min, followed by incubation with Protein Block Serum (DakoCytomation, Glostrup, Denmark) to decrease nonspecific binding. Then, the sections were incubated overnight at 4 °C with primary antibodies against IL-33 (diluted 1:100, rabbit polyclonal, Medical & Biological Laboratories, Nagoya, Japan), ST2 (diluted 1:100, mouse monoclonal, Medical & Biological Laboratories), mast cell tryptase (diluted 1:1000, mouse monoclonal, Dako), and CD34 (diluted 1:50, mouse monoclonal, Dako). The sections were incubated with secondary antibodies conjugated to a peroxidase-labeled polymer (EnVision™+ system, Dako) at room temperature for 30 min. Immune complexes were detected using 3,3′-diaminobenzidine tetrahydrochloride, and the sections were counterstained with hematoxylin. The specificities of the staining reactions were confirmed using nonimmune serum instead of the primary antibody.

Table 1
Relationship between clinicopathological features and expression of IL-33, ST2, and MCD.

Characteristic		Samples	Number of high IL-33 expression (%)	*p*	Number of high ST2 expression (%)	*p*	Number of high MCD (%)	*p*
Sex	Male	50	24 (48.0)	0.550	25 (50.0)	0.888	25 (50.0)	0.888
	Female	31	17 (54.8)		16 (51.6)		16 (51.6)	
Age	≦60	40	17 (42.5)	0.149	20 (50.0)	0.913	21 (52.5)	0.738
	>60	41	24 (58.5)		21 (51.2)		20 (48.8)	
Histologic type	WD	70	37 (52.9)	0.349	37 (52.9)	0.349	36 (51.4)	0.756
	MD/PD	11	4 (36.4)		4 (36.4)		5 (45.5)	
T classification	T1 + T2	67	32 (47.8)	0.379	32 (47.8)	0.379	32 (47.8)	0.379
	T3 + T4	14	9 (64.3)		9 (64.3)		9 (64.3)	
N classification	pN0	62	32 (51.6)	0.798	34 (54.8)	0.198	35 (56.5)	0.070
	pN1-3	19	9 (47.4)		7 (36.8)		6 (31.6)	
Stage	I + II	55	25 (45.5)	0.176	26 (47.3)	0.381	27 (49.1)	0.689
	III + IV	26	16 (61.5)		15 (57.7)		14 (53.8)	
Local recurrence	Negative	71	32 (45.1)	0.014*	34 (47.9)	0.312	35 (49.3)	0.737
	Positive	10	9 (90.0)		7 (70.0)		6 (60.0)	
Nodal recurrence	Negative	61	26 (42.6)	0.019*	25 (41.0)	0.004*	25 (41.0)	0.004*
	Positive	20	15 (75.0)		16 (80.0)		16 (80.0)	
Distant metastatic recurrence	Negative	78	38 (48.7)	0.241	40 (51.3)	0.616	39 (50.0)	1.000
	Positive	3	3 (100.0)		1 (33.3)		2 (66.7)	

WD, well differentiated; MD, moderately differentiated; PD, poorly differentiated.
* Significance.

2.3. IL-33 and ST2 expression and mast cell density (MCD)

Two investigators with no prior knowledge of the clinical data assessed the microvessel counts and expression of IL-33, ST2, and tryptase.

Staining results for IL-33 and ST2 were classified by estimating the percentage of tumor cells showing specific immunoreactivity. Two areas with a high density of stained cells were selected in a 40× field, following which the number of immunoreactive cells and the total number of tumor cells were counted in two areas in a 200× field. The percentage of positive cells calculated as an average of two counts was used as the expression score. The antibody against tryptase was used to determine MCD in the stroma surrounding the tumor and was classified by estimating the percentage of tryptase-positive cells in the stroma. The two areas with the highest MCD were identified in a 200× field. Then, the number of tryptase-positive cells and the total number of stromal cells were counted in these areas in a 400× field. To correlate these results with prognosis, the expression scores and MCD values were divided into high and low groups using median scores as cutoff values.

2.4. Microvessel density (MVD)

MVD was calculated by counting the number of vessels stained with CD-34 according to Weidner et al. [27]. Three areas with the highest MVD were selected in a 40× to 100× field. Then, microvessels were counted in the three areas in a 200× field. MVD was calculated as the average of three counts. Any brownish-staining endothelial cell or endothelial cell cluster was considered as a single microvessel.

2.5. Statistical analysis

IBM SPSS Statistics version 19 (IBM, Armonk, New York, USA) was used for data analysis. The clinical characteristics of patients in terms of IL-33 and ST2 expression and MCD were analyzed using Fisher's exact test and the chi-square test. The relationship between IL-33 and ST2 expression and MCD was evaluated using Spearman's rank correlation coefficient. Survival curves were evaluated using the Kaplan–Meier method, and differences between curves were analyzed using the log-rank test. IL-33 expression in relation to MVD was analyzed using the Mann–Whitney U test. A p value of <0.05 was considered statistically significant.

3. Results

3.1. IL-33 and ST2 expression

IL-33 was detected only in the nuclei of normal epithelial cells, and ST2 was observed most frequently, but faintly, in the membrane and cytoplasm of cells in the prickle cell to horny layers (Fig. 1A and 1B). In contrast, IL-33 was detected in the nuclei and cytoplasm of SCC cells (Fig. 1C). ST2 expression was most prominent in the membrane and cytoplasm of the tumor cells (Fig. 1D). IL-33 and ST2 expression were observed in 100% and 95.1% of the samples, respectively. The mean expression scores for IL-33 and ST2 in the tumor cells were $41.59 \pm 23.89\%$ and $22.14 \pm 19.29\%$, respectively.

3.2. MCD

MCs were detected by staining with the anti-tryptase antibody in all samples, and they were located in the stroma at the margins of the tumors (Fig. 1E). The mean MCD was $12.54 \pm 11.60\%$.

3.3. Correlation of IL-33 and ST2 expression with MCD

IL-33 expression correlated significantly with ST2 expression ($r = 0.558$, $p < 0.001$, Fig. 2A). IL-33 expression also correlated with MCD ($r = 0.626$, $p < 0.001$, Fig. 2B).

3.4. Association of IL-33 and ST2 expression and MCD with disease-free survival

To evaluate the prognostic value of IL-33 and ST2 expression and MCD in patients with tongue SCC, patients were stratified

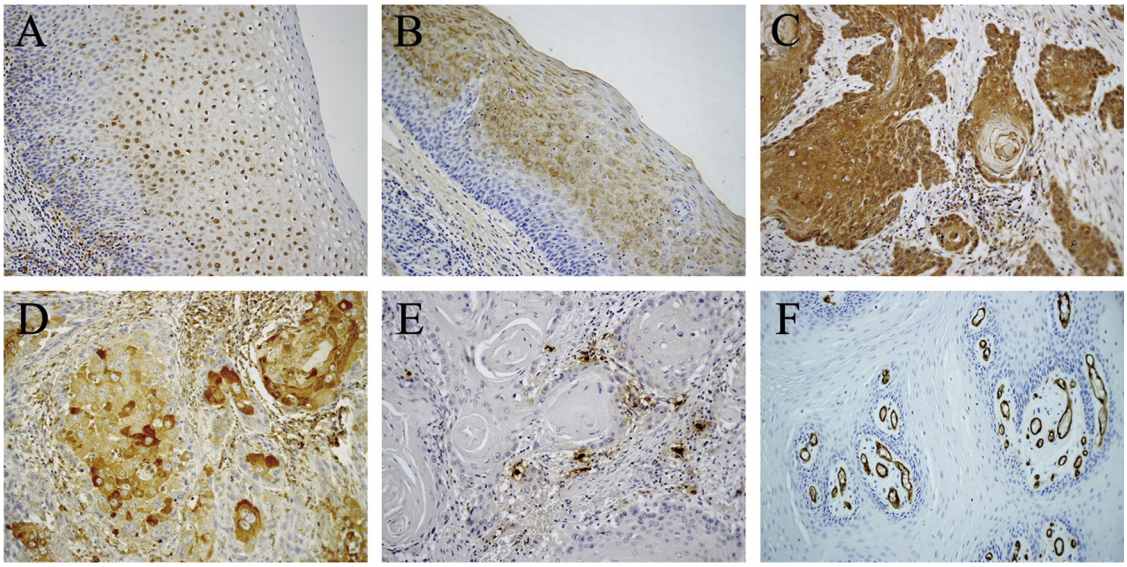

Fig. 1. Immunohistochemical analysis of IL-33 and ST2 expression in normal epithelial and tumor cells (A–D) and tryptase (E) and CD34 (F) expression (original magnification ×200).
(A) IL-33 is detected in the nuclei of normal epithelial cells. (B) ST2 is faintly detected in the membrane and cytoplasm of normal epithelial cells. (C) IL-33 is detected in the nuclei and cytoplasm of tumor cells. (D) Intense staining of ST2 in the membrane and cytoplasm of tumor cells. (E) MCs were detected as dark-brown stained cells using an anti-tryptase antibody. They were also located in the stroma at the tumor margins. (F) CD34 expression in vascular endothelial cells (stained dark brown) in the stroma of the tumor.

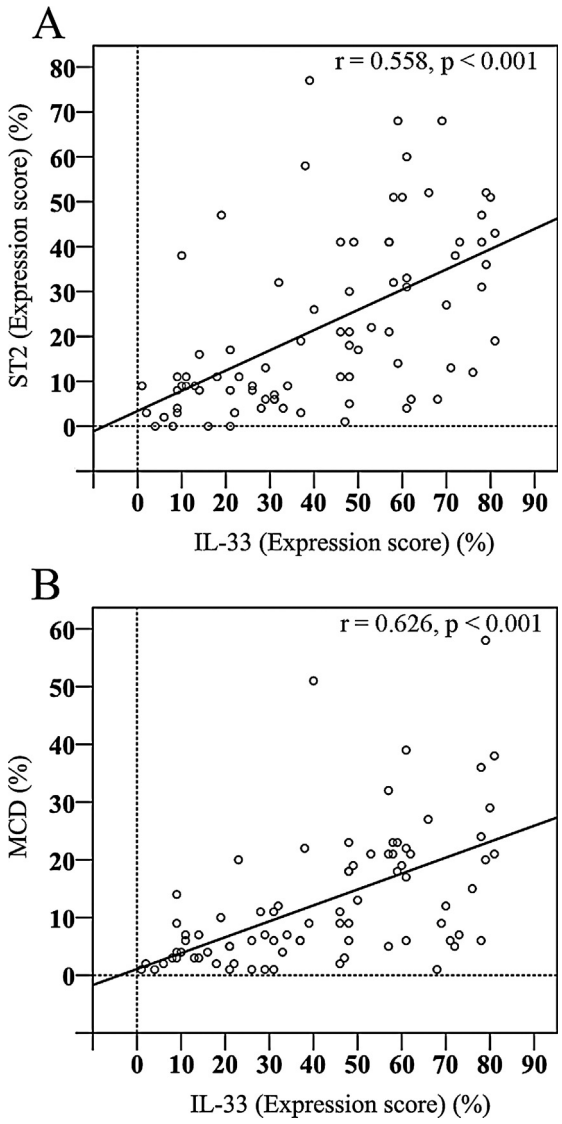

Fig. 2. Correlation between IL-33 and ST2 expression and MCD in tongue SCC. (A) Correlation between IL-33 and ST2 expression. IL-33 expression correlated significantly with ST2 expression (Spearman's rank correlation coefficient). (B) Correlation between IL-33 expression and MCD. IL-33 expression correlated significantly with MCD.

into high and low groups as described in Methods. The median expression scores for IL-33 and ST2 were 46% and 14%, respectively, and 9% for MCD. These scores were used as cutoff values. Of the 81 specimens, 41 were assigned to the high group. Kaplan–Meier survival analysis revealed that the prognosis was poorer for the high IL-33 and ST2 groups than for the low IL-33 and ST2 groups ($p = 0.004$ and 0.024, respectively, Fig. 3A and B). Similarly, the disease-free survival rate was significantly lower in the high MCD group than in the low MCD group ($p = 0.038$, Fig. 3C).

Furthermore, to examine the relationship of the prognosis of the high IL-33 patients with postoperative adjuvant therapy, Kaplan–Meier survival analysis was performed. Of the 41 patients assigned to the high IL-33 group, 14 patients underwent postoperative radiotherapy. Although the patients with postoperative treatment tended to have better prognosis than those without postoperative treatment, there was no significant difference between the two ($p = 0.145$ data not shown).

3.5. Relationship between clinicopathological features and expression of IL-33, ST2, and MCD

The relationship between immunohistochemical data and clinicopathological factors of the 81 patients, including age, sex, T classification, N classification, clinical stage, local recurrence, nodal recurrence, and distant metastatic recurrence was evaluated using Fisher's exact test and the chi-square test (Table 1). Local recurrence was significantly more frequent among patients in the high IL-33 group than among those in the low IL-33 group. IL-33 and ST2 expression and MCD were significantly associated with nodal recurrence. A higher frequency of nodal recurrence associated significantly with the high IL-33, ST2, and MCD groups, but not with the low groups. There were no other significant differences in clinicopathological features between the low and high IL-33, ST2, and MCD groups.

3.6. Relationship between IL-33 expression and MVD

Vascular endothelial cells reacted specifically with the antibody against CD34. The microvessels were detected as scattered structures in the stroma of the tumor (Fig. 1F). MVDs in all patients ranged from 7 to 75 (mean, 34.41 ± 16.46). The correlation between IL-33 expression and MVD is shown in Table 2. MVD was significantly higher in the high IL-33 group than in the low IL-33 group ($p < 0.001$).

4. Discussion

Little is known about the role of IL-33 in the pathogenesis and progression of carcinomas [18,19]. This is the first study, to our knowledge, that demonstrates IL-33 expression in tongue SCC and suggests its role in the progression of this tumor. We detected the expression of IL-33 and ST2 in patients with tongue SCC by immunohistochemistry and found that the expression of IL-33 was significantly correlated with poor prognosis.

We do not go further for the molecular mechanism which is attributable to the prognostic value of IL-33 in this study, however, one of the possible mechanism for IL-33-mediated malignant progression could be an activation of ST2 downstream signal transduction such as nuclear factor-κB (NF-κB). The IL-33/ST2 axis leads to activation of NF-κB [8,20,28], which is a key inducer of innate immunity and inflammation and has emerged as an important endogenous tumor promoter [6,29]. NF-κB activates the expression of genes encoding inflammatory cytokines, adhesion molecules, enzymes of the prostaglandin-synthesis pathway, inducible nitric oxide synthase, and angiogenic factors. Thus, activation of NF-κB through the IL-33 signaling pathway may cause cancer progression.

Th2-type responses induced by IL-33 may contribute to tumor progression. An induction of IL-33 enhances Th2 immune response and polarizes naïve T cells to produce IL-5 and IL-13 independently of IL-4 [8,20]. High levels of Th2 cytokines are observed in the tumor microenvironment and peripheral blood of patients with certain cancers [30]. Moreover, analysis of ST2-deficient mice demonstrates that the Th2-associated immune response is inhibited in the absence of IL-33/ST2 signaling, leading to delayed induction of mammary tumors and slower tumor growth and progression [31,32].

In addition, IL-33 induces angiogenesis and vasopermeability [33]. Our present study reveals that IL-33 expression strongly correlated with MVD and was significantly associated with local and nodal recurrence, but not clinical stage. These results suggest that IL-33 influences the malignant potential of the tumor through the promotion of angiogenesis and activation of ST2 signaling.

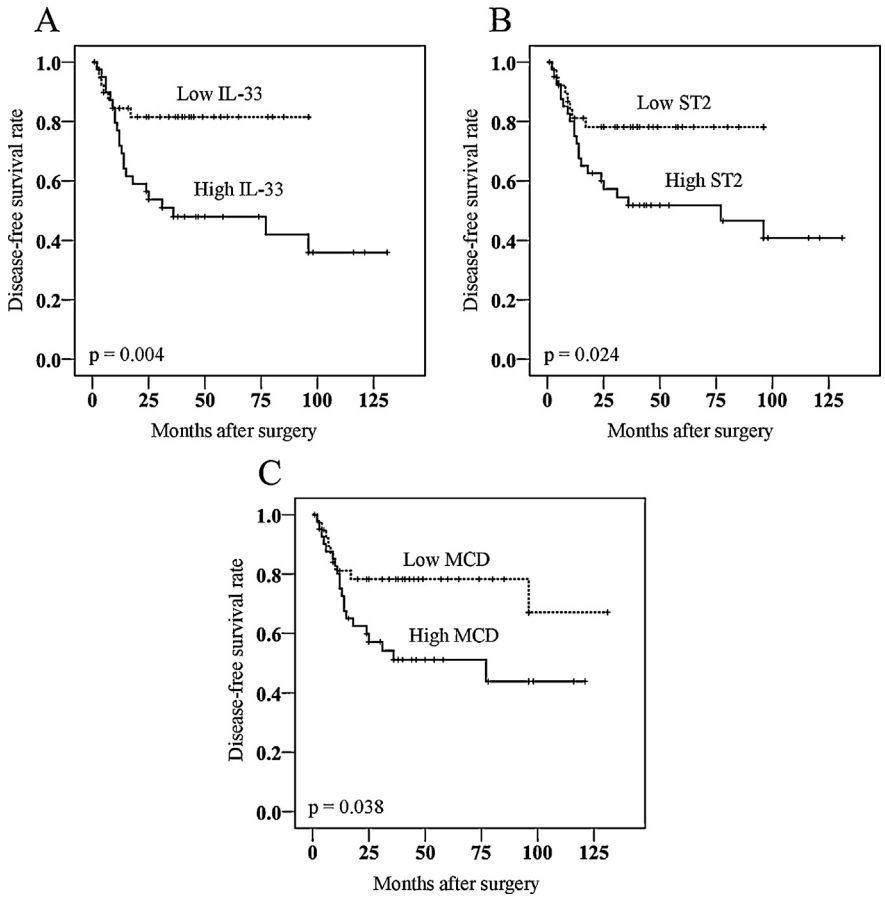

Fig. 3. Kaplan–Meier analysis of disease-free survival rates.
Differences between the curves were analyzed using the log-rank test. Disease-free survival rates in relation to IL-33 expression (A), ST2 expression (B), and MCD (C).

Table 2
Relationship between IL-33 expression and MVD.

		Number of patients	MVD (mean ± SD)	*p*
IL-33	High	41	43.46 ± 15.694	<0.001*
	Low	40	25.13 ± 11.346	

* Significance.

We also demonstrate that IL-33 expression significantly correlated with MCD, suggesting that IL-33 contributes to tumor progression by activating MCs. An induction of IL-33 potently activates the innate immune system by inducing pro-inflammatory cytokines and chemokine production through the activation of MCs. It also induces the degranulation of IgE-primed MCs and enhances their maturation and survival [8,20]. The MCD generally correlates with poor outcome in patients with tongue SCC [34,35]. Furthermore, other studies reveal that IL-33 activates macrophages, dendritic cells, eosinophils, and neutrophils [8,20]. These cells play important roles in enhancing an inflammatory environment that promotes tumor growth in the surrounding tissue [6]. IL-33 may recruit these inflammatory cells to the stroma of the tumor, subsequently enhancing tumor aggressiveness.

In conclusion, the high expression level of IL-33 is a risk factor for poor prognosis in patients with tongue SCC. In the high IL-33 patients, postoperative radiotherapy tended to improve the prognosis. Those patients that received postoperative radiotherapy were likely to have poor prognosis. Therefore, this result suggests that postoperative radiotherapy may be effective in the treatment of the high IL-33 patients with positive margins or pathologically positive lymph node metastasis.

IL-33 and ST2 may represent therapeutic targets for tongue SCC. Although it remains unclear how IL-33/ST2 axis contributes to tumor progression; our findings indicate that the IL-33/ST2 axis promotes the malignant potential of tumor by affecting the tumor as well as its microenvironment. Further investigation is needed to define the role of IL-33 in malignant potential.

Conflict of interest statement

None.

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