

Deregulation of cell adhesion molecules is associated with progression and poor outcomes in endometrial cancer: Analysis of The Cancer Genome Atlas data

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Abstract. Cell adhesion molecules (CAMs) determine the behavior of cancer cells during metastasis. Although some CAMs are dysregulated in certain types of cancer and are associated with cancer progression, to the best of our knowledge, a comprehensive study of CAMs has not been undertaken, particularly in endometrial cancer (EC). In the present study the expression of 225 CAMs in EC patients with various clinicopathological phenotypes were evaluated by statistical analysis using publicly available data from The Cancer Genome Atlas database. The Kaplan-Meier method, and univariate and multivariate Cox proportional hazards regression models were used for survival analyses. Among the differentially expressed CAMs that were associated with aggressive clinicopathological phenotypes, 10 CAM genes were independent prognostic factors compared with other clinicopathological prognostic factors, including stage, grade, age, lymph node status, peritoneal cytology and histological subtype. A total of six genes (L1 cell adhesion molecule, mucin 15, cell surface associated, cell adhesion associated, oncogene regulated, immunoglobulin superfamily member 9B, protocadherin 9 and protocadherin β 1) were selected for integrative analysis. The six-gene signature was demonstrated to be an independent prognostic factor and could effectively stratify patients with different risks. Patients with more high-expression CAMs had a higher risk of poor overall survival (OS) rate. The mortality risk for patients with elevation of >4 CAMs was

11 times of that in those without elevation of these 6 CAMs. Similar results were obtained when relapse-free survival (RFS) time was used during the analysis. Prognostic reliability of the six-gene model was validated using data of an independent cohort from the International Cancer Genome Consortium. In conclusion, a combination of CAM alterations contributed to progression and aggressiveness of EC. The six-gene signature was effective for predicting worse OS and RFS in patients with EC and could be complementary to the present clinical prognostic criteria.

Introduction

Endometrial cancer (EC) is a clinically heterogeneous disease (1). Although the majority of patients have favorable outcomes due to early symptoms and early treatment, those with high grade, high stage and serous type generally have a poor prognosis (1,2). Stratification of patients into different risk groups aids physicians in making clinical management decisions with respect to adjuvant chemotherapy and postoperative surveillance. Stratification is traditionally based on histological type, tumor grade, stage and lymph node invasion (1,3). However, interobserver disagreement in grade and histological type assignment is common (4,5). In addition, grade 3 tumors comprise a subset of ECs with significant differences in prognosis (6), and 8-10% of early-stage ECs develop recurrence and distant metastasis (7). High-throughput sequencing and bioinformatics analyses have revealed that cancers of the same grade and histological type may have distinct molecular and genomic profiles, which may account for the differences in patient outcomes. In 2013, based on a combination of somatic copy number alterations, tumor mutation burden, and microsatellite instability, The Cancer Genome Atlas (TCGA) database classified ECs into the following four molecular subtypes: Polymerase ϵ ultramutated (POLE), microsatellite instability (MSI) hypermutated, copy number low (CNL) and copy number high (CNH) (8). These molecular subtypes also have prognostic implications. However, determining these molecular subtypes require the next generation sequencing and bioinformatics analysis which are too expensive and cumbersome for widespread implementation in routine clinical practice (8). Therefore, more accurate molecular prognostic

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markers and improved approaches are required to identify patients who are at high-risk.

Metastasis, a process that involves dissociation, homing and growth of tumor cells in distant organs, is responsible for most cases of cancer-associated mortality (9). Adhesion to the extracellular matrix (ECM) is a critical process for tumor cells migration, in which a large group of diverse cell adhesion molecules (CAMs) serve a significant role in cell-cell interactions and the interaction between cells and ECM (10-13). The ECM is a natural niche for cell residence, where the CAM-mediated interaction with surface ligands leads to the activation of crucial signaling associated with cell proliferation, differentiation and spreading (10-13). Although the molecular events in numerous CAMs involved in dissemination are not fully understood, CAMs could be promising biomarkers for the diagnosis, prognosis and therapy of cancer metastasis. There are five main classes of CAMs: Immunoglobulin superfamily proteins, selectins, cadherins, integrins and mucins (13). Some CAMs are found dysregulated in several types of cancer and are associated with cancer progression and survival. For example, higher expression of L1 cell adhesion molecule (LICAM) is associated with poor survival in breast cancer, pancreatic cancer, colorectal cancer, ovarian cancer and endometrial cancer (14-16). Mucin 15, cell surface associated (MUC15), is overexpressed in glioma and papillary thyroid carcinoma and correlates with tumor progression (17,18). Cell adhesion associated, oncogene regulated (CDON), is detected in high-grade tumor, rather than low grade non-small cell lung cancer (19). The expression of immunoglobulin superfamily member 9B (IGSF9B) is associated with shorter survival in breast cancer patient (20). High expression of basal cell adhesion molecule (Lutheran blood group) (BCAM) is significantly associated with advanced stage of bladder cancer (21). CEA cell adhesion molecule 21 (CEACAM21) are overexpressed in the immune active samples of high grade serous ovarian cancers which showed a statistically significant better disease free survival over the immune silent one (22). Integrin subunit α L (ITGAL) constitutes one of the 10-gene expression signature that correlated with poor survival of renal cancer (23). However, a comprehensive study of the role of CAMs in cancer progression is lacking, particularly in EC. Based on the vital role of numerous CAMs in cancer (10-13) and their context-dependent expression in different tissues, we hypothesized that a set of CAMs different from that in other cancers may be up- or down-regulated in EC, and that their comprehensive effects determine the behavior of endometrial cancer cells during metastasis.

In the present study, the expression levels of 225 members of the CAM family were analyzed and the associations between these CAMs and outcomes in patients with EC were investigated using data from TCGA and the International Cancer Genome Consortium (ICGC) databases. The results of the present study may provide novel insights into the molecular pathogenesis of progression of EC, as well as identifying novel biomarker candidates.

Materials and methods

Source of data and sample selection. CAM genes were retrieved from the gene database of the National Center for Biotechnology Information (<https://www.ncbi.nlm.nih.gov/>).

A total of 225 genes belonging to cadherins, mucins, selectins, integrins, the immunoglobulin superfamily and other CAMs were included in the present study (Table SI). The mRNA expression data of Endometrial Carcinoma (EC; 583 cases; Dataset ID: TCGA-UCEC.htseq_fpk.m.tsv; version 10-27-2017), corresponding clinical information (605 cases; version 10-27-2017) and survival data (592 cases; version 10-27-2017) were downloaded from the University of California Santa Cruz (UCSC) Xena browser (<https://xenabrowser.net>). \log_2 (FPKM+1) transformed expression data were used for all of analyses. Normal solid tissue samples, as well as repeated and recurrent samples, were excluded. Finally, 543 cases with both sequencing data of the primary tumor and clinicopathological data were selected and used in the analyses. Information regarding the molecular subtypes of these cases was obtained from cBioportal [www.cbioportal.org; Dataset, Uterine Corpus Endometrial Carcinoma (TCGA, Nature 2013)], in which 232 patients with complete sequencing data were divided into four groups (POLE, MSI, CNL and CNH) based on a combination of somatic copy number alterations, tumor mutation burden and microsatellite instability. Data from an independent cohort from ICGC (24) were downloaded from UCSC Xena browser, 504 cases with both expression (dataset, gene expression RNAseq-US projects) and survival data (dataset, phenotype-OS) of EC were selected and used for validation. Immunohistochemistry (IHC) results of some CAMs on EC samples were obtained by searching the Human Protein Atlas database (HPA; <http://www.proteinatlas.org>).

Statistical analysis. Statistical analysis was performed using GraphPad Prism software (v.7.0; GraphPad Software, Inc.) and the Statistical Package for Social Sciences for Windows (v.20.0; IBM Corp.). The normality of data distribution was evaluated using the Shapiro-Wilk test. The Student's t-test and Mann-Whitney U-test were used to compare the means between two groups for normally and non-normally distributed continuous data, respectively. For comparisons among three or more groups, one-way analysis of variance and Kruskal-Wallis test were used for normally and non-normally distributed continuous data, respectively. VennPainter V.1.2.0 (<https://github.com/linguoliang/VennPainter/releases>) was used to show the shared sets of differentially expressed genes (DEGs) among different clinicopathological categories. The Kaplan-Meier method was used to compare relapse-free survival (RFS) and overall survival (OS) between different groups, and the log-rank test was used to examine the statistical significance. RFS was defined as time from surgery to the date of tumor recurrence, metastasis or mortality. OS of patients was calculated from the date of initial diagnosis to the date of death or last follow-up, and expressed in terms of days. All cases of mortality were considered as events, irrespective of the cause. The Cox proportional hazards regression model was used for multivariate analysis to compare the influence of expression of CAMs on survival along with other clinicopathological characteristics, including stage, grade, age, lymph node status, peritoneal cytology and histological subtype. Only covariates significantly associated with outcomes in univariate analysis were included in multivariate Cox regression analysis. The backward method was selected for entering variables into

the multivariate Cox regression model. Results were reported as hazard ratios (HRs) with 95% CIs. For survival analysis, patients were divided into high- and low-expression groups using optimum cut-off points determined using the X-tile software v3.6.1 (25). A total of 334 cases were available for multivariate Cox analysis after the incomplete data were excluded. $P < 0.05$ was considered to indicate a statistically significant difference.

Results

Processing and classification of patients' clinical data. Through analysis of the clinical data, 543 primary tumors were stratified into different prognostic risk groups according to International Federation of Gynecology and Obstetrics stage (26), histological subtype (3), tumor pathological grade (3), lymph nodes status, peritoneal cytology, and recurrence and metastasis following treatment (Table I). The four molecular subtypes for 232 samples are also shown in Table I. Patient age ranged between 31 and 90 years, with a median age of 66 years. The follow-up time ranged between 4 and 6,859 days, with a median follow-up time of 909 days.

Expression of CAMs and their association with clinicopathological features in patients with EC. By analyzing the expression levels of 225 members of the CAM family (Table SI), differentially expressed CAMs were identified in samples of different clinicopathological and molecular phenotypes, including 72 in different stages, 120 in different grades, 131 in different histological types, 129 in different molecular subtypes, 76 in samples with different lymph nodes status and 46 in samples with different peritoneal cytology status. Additionally, 35 differentially expressed genes (DEGs) were found in patients with local recurrence or distant metastasis compared to those without recurrence or metastasis. Of these 35 DEGs, 13 were upregulated and 22 downregulated. The VennPainter diagram was used to show the shared sets of DEGs and possible associations among the seven clinicopathological categories (Fig. 1). Overlapping genes were considered to be more reliable. The results revealed that 10 DEGs were shared in all seven clinicopathological categories. There were 13 genes co-differentially expressed in six clinicopathological categories, and 28 genes were co-differentially expressed in five clinicopathological categories (Fig. 1). Representative graphs of two differentially expressed CAMs in patients evaluated with different clinicopathological categories are shown in Fig. 2.

Association between the expression levels of CAMs and the survival time of patients. Genes that were co-differentially expressed in >5 clinicopathological categories were selected for Kaplan-Meier analysis in which X-tile-determined cutoff points were used to divide patients into high- and low-expression groups. The results demonstrated that worse OS was associated with higher expression levels of 21 CAM genes and lower expression levels of 7 CAM genes ($P < 0.05$; Table SII). LICAM exhibited the best separation of survival curves between the high- and low-expression groups, with the highest χ^2 value and the lowest P-value. The association between the expression of 28 CAMs and the OS of the patients was

Table I. Characteristics of patients with endometrial cancer downloaded from The Cancer Genome Atlas database.

Characteristic	Patients, n	Percentage
FIGO stage	543	
I	339	62.43
II	51	9.39
III	124	22.84
IV	29	5.34
Histological type	543	
Endometrioid	407	74.95
Mixed	22	4.05
Serous	114	21.00
Pathology grade	543	
G1	98	18.05
G2	120	22.10
G3	325	59.85
Lymph node	447	
Positive	84	18.79
Negative	363	81.21
Peritoneal cytology	407	
Positive	57	14.00
Negative	350	86.00
Molecular subtype	232	
POLE	17	7.33
MSI	65	28.02
CNL	90	38.79
CNH	60	25.86
Recurrence and metastasis	463	
Positive	70	15.12
Negative	393	84.88

POLE, polymerase ϵ ultramutated; MSI, microsatellite instability; CNL, copy number low; CNH, copy number high; FIGO, International Federation of Gynecology and Obstetrics.

further confirmed using univariate Cox regression analysis ($P < 0.01$ for all; Table SIII). Subsequently, these genes were analyzed using multivariate Cox regression analysis and the aforementioned X-tile-determined cutoff points. Of the 28 CAM genes, 10 were prognostic factors for OS independent of other clinical risk factors, including stage, grade, age, lymph node status, peritoneal cytology and histological subtype (Table II). A worse prognosis in patients with EC was significantly associated with higher expression levels of LICAM, MUC15, CDON, IGSF9B, BCAM, protocadherin 9 (PCDH9) and protocadherin $\beta 1$ (PCDH1) and lower expression levels of ITGAL, immunoglobulin superfamily member 6 (IGSF6) and CEACAM21 (Table II). LICAM was the most prominent prognostic biomarker with a HR of 2.973 (95% CI, 1.529-5.782). The association between the expression levels of these CAMs and the RFS of the patients was also analyzed, and similar results were obtained, with the exception of MUC15 (Table II).

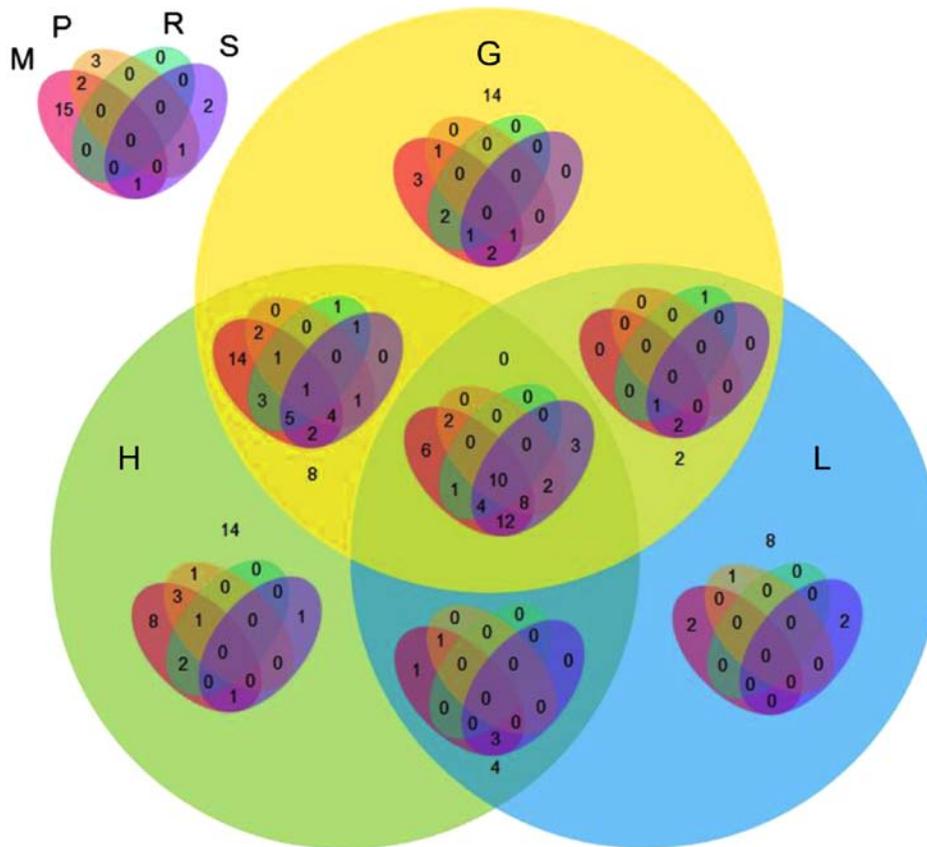


Figure 1. VennPainter diagram revealing the overlap of seven sets of differentially expressed genes in endometrial cancer. The number presented in the Venn diagram represents the number of co-dysregulated genes in different clinicopathological categories. G, grade; S, stage; H, histology; M, molecular subtype; L, lymph node; P, peritoneal cytology; R, recurrence and metastasis.

Combinational Kaplan-Meier analysis. Numerous CAMs, rather than a single molecule, were found to be dysregulated and associated with worse prognosis of patients with EC; therefore, the invasion- and metastasis-promoting effect may be due to the combined function of these molecules. Therefore, combinational Kaplan-Meier analysis of the 10 CAMs that were identified to be independent prognostic factors by multivariate Cox regression analysis was performed. Patients with a higher number of dysregulated CAMs had a higher risk of worse OS, as shown in the multicategory Kaplan-Meier plot (Fig. 3A), in which patients were stratified by the number of dysregulated CAMs.

Development of a classifier with a six-gene signature. Although combinational analysis of the 10 CAMs could predict prognosis, a lower number of genes would be more desirable. Therefore, a six-gene signature (L1CAM, MUC15, CDON, IGSF9B, PCDH9 and PCDHB1) was developed to evaluate the prognosis of patients. All six genes were unfavorable prognostic markers. They were selected for the following reasons: Firstly, patients were well stratified using the six-gene model. Secondly, their expression features provide the possibility to use simple laboratory methods to classify patients for risk stratification. In this six-gene model, patients were stratified into four groups according to the number of highly expressed CAMs (Fig. 3B). As shown by the multicategory Kaplan-Meier plots, the six-gene model was a better predictor of overall survival rate compared with grade (Fig. 3C), stage (Fig. 3D), molecular subtype (Fig. 3E)

and expression of L1CAM alone (Fig. 3F). Moreover, the six-gene model also stratified heterogeneous stage I (339 cases; Fig. 3G) and grade 3 (325 cases; Fig. 3H) patients into different risk groups, thereby refining the prognosis. Similar results were obtained when RFS was analyzed (Fig. 3I-K). Additionally, the six-gene signature was demonstrated to be an independent prognostic factor by multivariate Cox regression analysis. The death risk of patients with elevation of >4 CAMs in their samples was 11-fold higher compare with those without elevation of these six CAMs (HR, 11.175; 95% CI, 3.217-38.816; $P < 0.001$), while the risk of recurrence and metastasis was about 3-fold higher for patients with elevation of >4 CAMs in their samples compared with those without elevation (HR, 3.360; 95% CI, 1.558-7.248; $P = 0.002$; Table II).

Validation of the reliability of the six-gene model using ICGC data. The prognostic reliability of the six-gene model was validated using data from ICGC. Consistent with the result using data from TCGA, higher expression levels of these six genes were associated with worse OS, as analyzed using Kaplan-Meier and univariate Cox regression methods (Table SIII). Patients from the ICGC cohort could also be stratified into four risk groups according to the number of highly expressed CAMs (Fig. 3L).

Association between the six-gene signature and clinicopathological features. The composition ratios of different clinicopathological phenotypes in the groups stratified by the

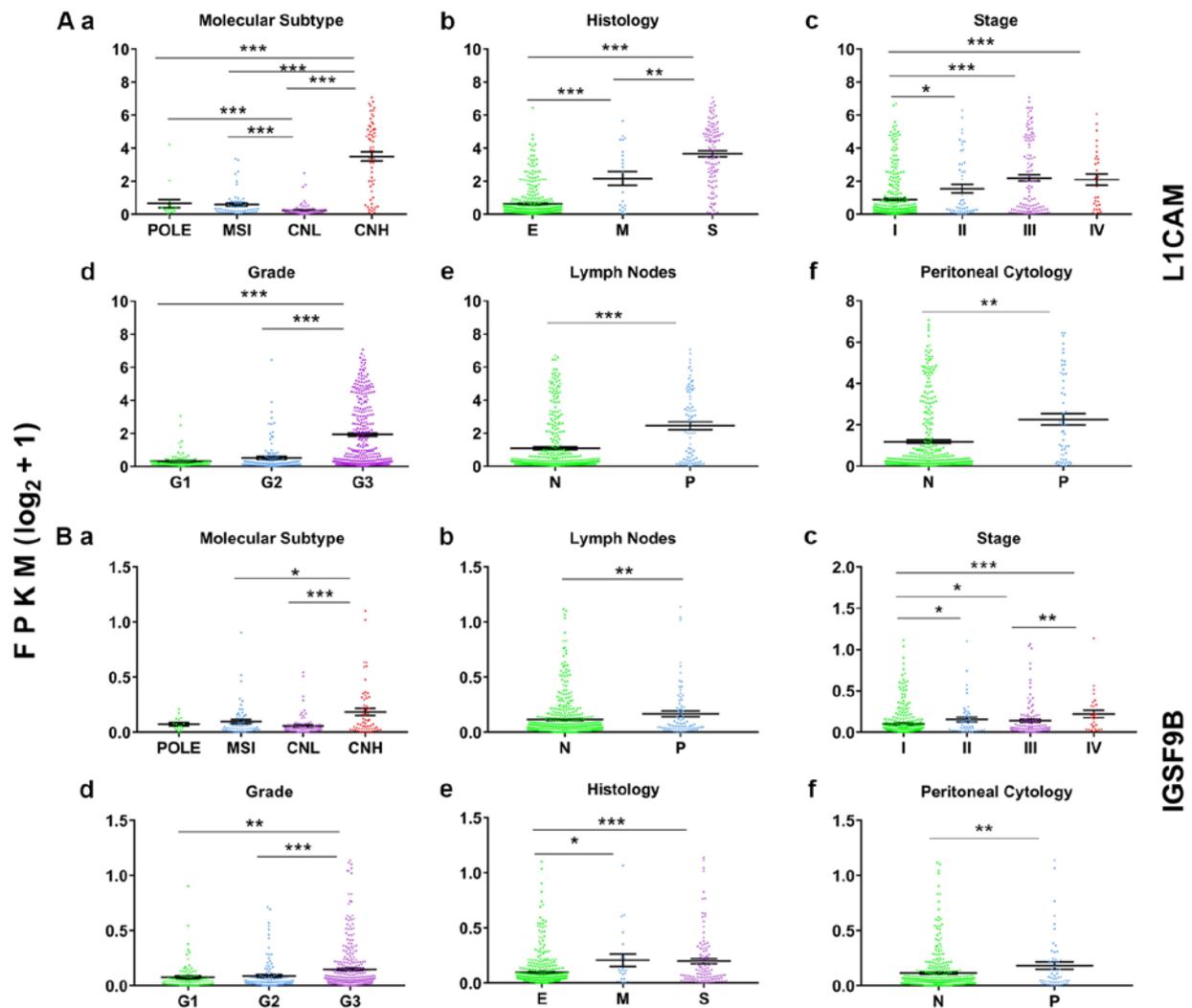


Figure 2. Representative graphs of the differentially expressed CAMs in patients with endometrial cancer and classified by different clinicopathological categories. Expression level and characteristics of L1CAM (Aa-Af) and IGSF9B (Ba-Bf) are shown with respect to molecular subtypes (Aa and Ba), histological types (Ab and Bb), stages (Ac and Bc), grades (Ad and Bd), lymph node status (Ae and Be) and peritoneal washing cytology status (Af and Bf). * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. N, negative; P, positive; E, endometrioid; M, mixed; S, serous; FPKM, Fragments Per Kilobase of transcript per Million mapped reads; POLE, polymerase ϵ ultramutated; MSI, microsatellite instability; CNL, copy number low; CNH, copy number high; G, grade.

six-gene model were investigated. An increasing number of grade 3 cases, advanced stage, serous type, CNH, recurrence and metastasis, positive peritoneal cytology, and lymph node invasion were identified in groups with more highly expressed CAMs (Fig. 4). Patients with none of these six genes above the cut-off values had a 5-year survival rate of 94.3%. However, patients with 1, 2-3 and 4-6 genes above the cut-off values had 5-year survival rates of 81.7, 66.4 and 41.6%, respectively (Fig. 4).

Expression features of the six CAM genes. The expression values of the six genes had similar characteristic distribution patterns. Most of the samples were convergently distributed at minimum levels (Fig. S1). Low expression samples accounted for a high proportion in less aggressive clinicopathological phenotypes such as grade I, grade II, endometrioid, stage I and less aggressive molecular subtypes (POLE, MSI, and CNL). High expression samples constituted a relatively high proportion in aggressive clinicopathological phenotypes, such as grade 3, serous, stage IV and molecular subtype CNH (Fig. 2).

By searching the HPA database, IHC staining results of L1CAM, CDON, IGSF9B and PCDHB1 in EC were obtained (Fig. S2). These four CAM genes exhibited special features when examined by IHC. Firstly, positively stained cells were scattered or clustered in their distribution, which made it easy to distinguish from homogeneous non-specific staining. Second, most of the samples presented on HPA website were negatively stained, which was in accordance with the phenomenon that most of the samples exhibited extremely low mRNA expression levels. The features of expression may have some advantages that can be useful in clinical practice. IHC-positive results were not found for MUC15 in the 24 EC samples presented in the HPA database, although scattered positively stained cells were seen in lung and ovarian cancer. IHC results were not presented for PCDH9 in any cancer.

Discussion

CAMs are a large class of cell surface molecules that consists of >200 members in five families; although several CAM

Table II. Multivariate Cox regression analysis of prognostic factors for overall survival and relapse-free survival.

Prognostic variables	Overall survival			Relapse-free survival		
	P-value	HR	95% CI	P-value	HR	95% CI
Individual genes						
CDON	0.007	2.417	1.270-4.602	0.017	1.958	1.130-3.391
L1CAM	0.001	2.973	1.529-5.782	0.003	2.019	1.263-3.227
PCDH9	0.025	2.033	1.094-3.779	0.046	1.624	1.007-2.617
PCDHB1	0.009	2.307	1.235-4.309	0.010	1.994	1.180-3.369
BCAM	0.015	2.052	1.149-3.665	0.005	1.907	1.211-3.001
MUC15	0.029	1.884	1.065-3.332	0.653	1.115	0.694-1.790
IGSF9B	0.015	2.115	1.157-3.866	0.042	1.711	1.020-2.867
ITGAL	0.015	0.503	0.289-0.875	0.009	0.550	0.351-0.859
CEACAM21	0.011	0.422	0.218-0.817	0.006	0.480	0.285-0.807
IGSF6	0.006	0.411	0.218-0.775	0.004	0.490	0.302-0.793
Six-gene signature						
All 6 genes < cut-off value	<0.001			0.001		
1 gene > cut-off value	0.15	2.564	0.712-9.225	0.953	1.023	0.472-2.214
2-3 genes > cut-off value	0.011	4.909	1.440-16.734	0.042	2.067	1.028-4.157
4-6 genes > cut-off value	<0.001	11.175	3.217-38.816	0.002	3.360	1.558-7.248

The backward method was selected for the multivariate Cox regression analysis. HR, hazard ratio; L1CAM, L1 cell adhesion molecule; IGSF9B, immunoglobulin superfamily member 9B; PCDH9, protocadherin 9; PCDHB1, protocadherin β 1; CDON, cell adhesion associated, oncogene regulated; MUC15, mucin 15, cell surface associated; BCAM, basal cell adhesion molecule (Lutheran blood group); ITGAL, integrin subunit α L; CEACAM21, CEA cell adhesion molecule 21; IGSF6, immunoglobulin superfamily member 6.

genes mentioned earlier are known for their involvement in different aspects of cancer biology (11), comprehensive study of all CAM genes is lacking. In the present study, the expression levels of 225 members of the CAM family in EC were analyzed using data downloaded from TCGA, and the expression changes of all CAMs among patients with EC, with various clinicopathological phenotypes were also investigated. The present study demonstrated that a number of CAMs were differentially expressed and associated with aggressive clinicopathological phenotypes. The dysregulated CAMs in EC included members of the cadherins, integrins, mucins and the immunoglobulin superfamily. These CAMs may have different responsibilities in different aspects of cell adhesion, including homophilic cell adhesion, heterophilic cell adhesion and cell-matrix interactions (13). A total of 28 CAM genes were associated with the prognosis of patients with EC, 10 of which were demonstrated to be independent prognostic factors for OS. When the 10 CAMs were analyzed in combination, patients with a higher number of dysregulated CAMs had a higher risk of worse OS. These results indicated a synergistic biological role of these CAMs in the progression and aggressiveness of EC. However, little is known regarding the exact roles of these CAMs in EC, with the exception of L1CAM.

In EC, L1CAM was the most prominent prognostic biomarker among all of the CAMs. L1CAM is normally highly expressed in neural systems, and it performs an essential role in the development and plasticity of the nervous system (14). L1CAM has been identified as a

prognostic marker for a wide spectrum of malignancies, including melanoma, neuroblastoma, and prostate, pancreatic, breast, ovarian, colorectal, head and neck, and non-small cell lung cancer, as well as EC (14-16). It serves important roles in different steps of cancer progression, such as cell proliferation and apoptosis, adhesion and migration, and the epithelial-mesenchymal transition process (14-16). Other CAMs, including MUC15, CDON, IGSF9B, BCAM, CEACAM21 and ITGAL, have been associated with progression and/or prognosis of several types of cancer as mentioned in the introduction section (17-23), but their association with EC has not been reported. To the best of our knowledge, no association with cancer has been reported for PCDHB1, IGSF6 and PCDH9.

In survival analysis, patients are often classified by whether they fall above or below the median expression level. However, the expression values of many genes in tumor tissues are not normally distributed. Proper statistic methods are important in analyzing these data. It has been reported that median cut-off point approach would miss detecting 23% of the genes that were significantly associated with survival at lower or higher expression cut-points in patients with diffuse large B cell lymphoma (27). X-tile, which uses the maximum statistic to define the best categorization of patients, is a powerful tool to explore the association of gene expression data with outcomes (25). Due to the skewed distribution of some CAM expression levels in patients with EC, the X-tile-determined cut-off values were used for Kaplan-Meier and Cox regression analysis in the present study.

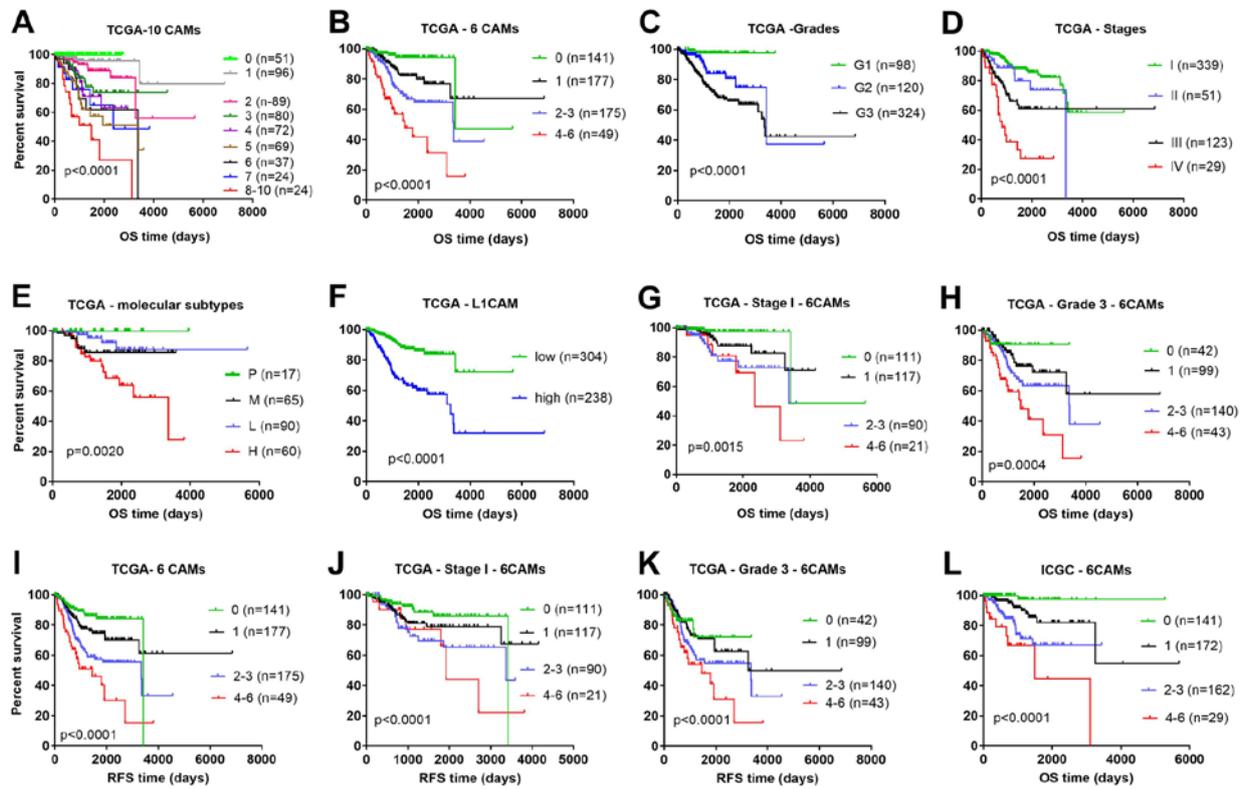


Figure 3. Comparison of different prognostic factors in OS and RFS analysis using the Kaplan-Meier method. OS for patients stratified into (A) nine groups and (B) four groups according to the number of high expression CAM genes, from the TCGA dataset. The OS of patients stratified by different (C) grades, (D) stages, (E) molecular subtypes and (F) expression levels of L1CAM from TCGA database. The OS for patients stratified according to the number of highly expressed CAM genes for (G) Stage I and (H) Grade 3 from the TCGA dataset. The RFS for patients stratified by (I) the number of highly expressed CAM genes, (J) the number of highly expressed CAM genes with Stage I and (K) the number of highly expressed CAM genes with Grade 3, from the TCGA dataset. (L) OS for patients from the ICGC dataset stratified according to the number of highly expressed CAM genes. One case with OS time of -6 days was excluded from TCGA cohort in all Kaplan-Meier analyses. 0, none of the six genes were above the cut-off value; 1, one gene was above the cut-off value; 2-3, two to three genes were above the cut-off values; 4-6, four to six genes were above the cut-off values. CAM, cell adhesion molecules; ICGC, International Cancer Genome Consortium; OS, overall survival; RFS relapse-free survival; P, polymerase ϵ ultramutated; M, microsatellite instability; L, copy number low; H CNH, copy number high; TCGA, The Cancer Genome Atlas; G, grade.

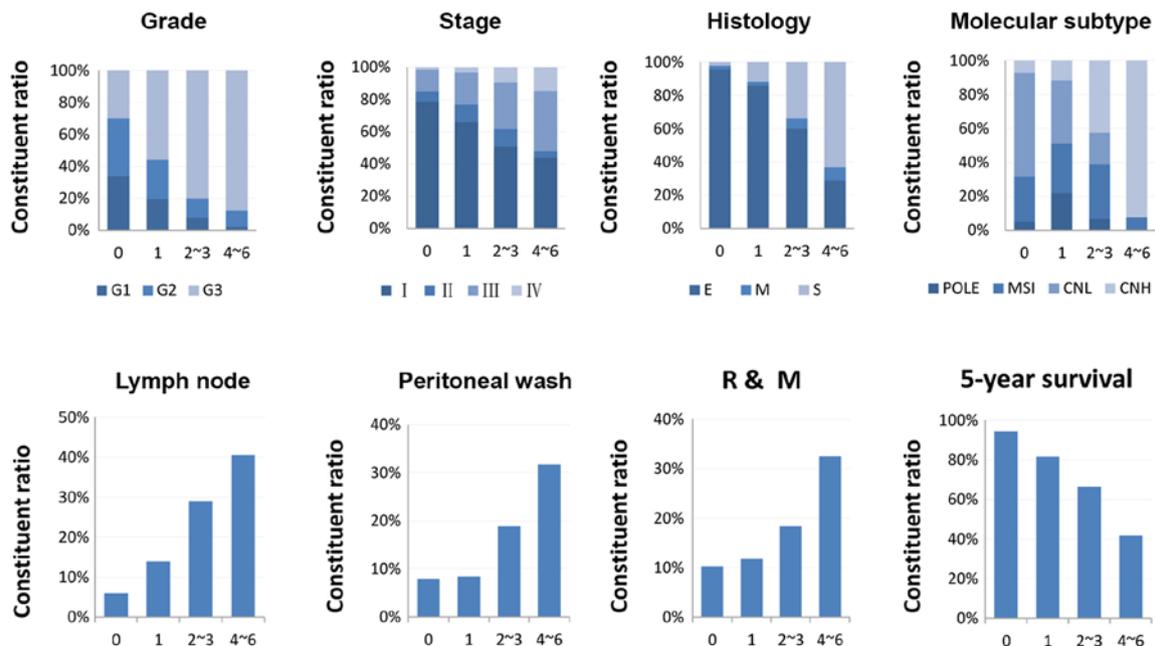


Figure 4. Association between the six-gene signature and clinicopathological features. Patients were stratified into four groups: 0, none of the six genes were above the cut-off values (n=141); 1, one gene above the cut-off point (n=177); 2-3, two to three genes were above the cut-off values (n=175); 4-6, four to six genes were above the cut-off values (n=49). One case with an overall survival time of -6 days was excluded. R, recurrence; M, metastasis; G, grade; E, endometrioid; M, mixed; S, serous; POLE, polymerase ϵ ultramutated; MSI, microsatellite instability; CNL, copy number low; CNH, copy number high.

In consideration of practical clinical application, a six-gene signature was established to evaluate the prognosis of patients. Multivariate Cox regression analysis revealed that the six-gene combination was an independent prognostic factor and was effective for predicting worse OS and RFS in patients with EC. Patients with more highly expressed CAMs had a higher risk of worse survival. The prognostic reliability of the six-gene model was validated using data of an independent cohort from ICGC. The slightly inferior level of stratification in the ICGC cohort compared with that in the TCGA cohort may be due to the difference in the patients' composition of the clinicopathological subtype. Unfortunately, the clinicopathological characteristics of the ICGC cohort were not available for multivariate Cox regression analysis. The effect of the six-gene signature in stratifying patients with different risks was effective compared with that of several routine clinical prognostic factors in the same cohort and could be complementary to the present clinical prognostic criteria.

The six genes selected in the combination analysis possessed the following features: Firstly, extremely low expression was present in most of the samples and high expression was present in a small number of samples with wide discrepancy. Accordingly, these genes were negatively stained by IHC in most of the samples presented on HPA website. Secondly, positively stained cells were scattered or clustered in their distribution on IHC slides. As examining mRNAs by the second-generation sequencing is more sensitive compared with examining proteins by IHC, it is hypothesized that the extremely low mRNA expression of these genes may result in negative staining on IHC, while high mRNA expression may result in positive staining. These features make the six CAM genes promising for routine clinical application as it is easier to judge between negative and positive staining than to define weak or strong staining on IHC, and the scattered positive cancer cells are easy to distinguish from homogeneous non-specific staining. Since the amount of IHC detected samples presented in the HPA database is limited, the positive rate of IHC detection with the proportion of high mRNA expression samples could not be compared. Therefore, the potential prognostic role and the true clinical value of these CAMs require further validation by multi-medical center studies using more practical and reliable methods, such as quantitative PCR and IHC.

The present study demonstrated that dysregulation of CAMs is an important feature characterizing the most aggressive EC, which may facilitate further study on the oncogenic role of CAMs in the progression of EC and a deeper understanding of the orchestral function of CAMs in the progression of EC. The six-gene prognostic signature may enable refinement of EC prognosis and allow further studies and tailored treatment on the basis of biological considerations.

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Availability of data and materials

All data generated or analyzed during the present study are included in this published article.

Authors' contributions

XH and JW were involved in the conception and design of the study. XH and LM participated in the retrieval of CAM genes and literature searches. XH, LM and SL were involved in data curation and validation. SL, QZ and NL statistically analyzed data and created figures and tables. XH wrote the manuscript. JW and SL reviewed and edited the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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