

# RETRACTED ARTICLE: Identification and Validation of Biglycan as Prognosis and Therapy Markers for Patients with Stomach Adenocarcinoma

Changming Shao<sup>1,\*</sup>  
Chunfa Cheng<sup>2,\*</sup>  
Qinshu Shao<sup>3</sup>  
Bing Chen<sup>1</sup>

<sup>1</sup>Department of Vascular Surgery, The Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou, 310000, Zhejiang, People's Republic of China; <sup>2</sup>Department of Vascular Surgery, The First People's Hospital of Yuhang District, Hangzhou, 311100, Zhejiang, People's Republic of China; <sup>3</sup>Department of General Surgery, Zhejiang Provincial People's Hospital, Hangzhou, 310009, Zhejiang, People's Republic of China

\*These authors contributed equally to this work

Correspondence: Bing Chen  
Department of Vascular Surgery, The Second Affiliated Hospital, Zhejiang University School of Medicine, 1511 Jianghong Road, Binjiang District, Hangzhou, 310000, Zhejiang, People's Republic of China  
Email 2114008@zju.edu.cn

Qinshu Shao  
Department of General Surgery, Zhejiang Provincial People's Hospital, 158 Shangtang Road, Xiacheng District, Hangzhou, 310009, Zhejiang, People's Republic of China  
Email chmshao@126.com

**Objective:** Previous studies have confirmed the biglycan (BGN) as a core gene in stomach adenocarcinoma (STAD). Present study aimed at conducting further investigations to reveal the potential function of BGN in STAD.

**Methods:** The mRNA and protein expressions of BGN in STAD were firstly evaluated, followed by immune infiltration analyses. The influence of BGN expression on the overall survival of STAD patients was subsequently analyzed, and a restrict survival analysis was performed as well. The protein-protein interaction (PPI) network analysis on the co-expressed genes with BGN was finally adopted to obtain the most important module in the whole network, and significant Kyoto Encyclopedia of Genes and Genomes (KEGG) pathway associated with hub genes within the main module was further predicted.

**Results:** (1) We verified the mRNA high expression of BGN in STAD (all  $P < 0.05$ ), and higher expression was observed in patients with stage 4 ( $P < 0.001$ ) and grade 3 ( $P < 0.001$ ). The BGN protein was mainly localized to the golgi apparatus, and protein expression displayed an individual difference. (2) Immune infiltration analysis showed the strongest correlation between BGN expression and abundance of natural killer cell ( $P < 0.001$ ), Transforming Growth Factor beta 1 (TGFB1) ( $P < 0.001$ ), TNF Receptor Superfamily Member 4 (TNFRSF4) ( $P < 0.001$ ) and C-X-C Motif Chemokine Ligand 12 (CXCL12) ( $P < 0.001$ ) in STAD. BGN expression was also correlated to immune subtypes ( $P = 0.0347$ ) and molecular subtypes ( $P = 0.0263$ ) in STAD. (3) High expression of BGN shortened the overall survival time of STAD patients (all  $P < 0.01$ ). The influence of BGN expression on the prognosis was statistically affected by several clinical phenotypes and cohorts of patients. Cox regression showed that BGN can be considered as a prognostic predictor of STAD ( $P < 0.05$ ). (4) Pathway analysis indicated that BGN possibly participated in ECM-receptor interaction, focal adhesion, human papillomavirus infection and PI3K-Akt signaling pathway (all  $P < 0.001$ ).

**Conclusion:** BGN was highly expressed in STAD, implying a poor prognosis of patients. Relevant signal pathways associated with BGN were distinguished as well. BGN could be used as a potential therapeutic biomarker for STAD.

**Keywords:** biglycan, stomach adenocarcinoma, high expression, immune infiltration, prognosis

## Introduction

Stomach adenocarcinoma (STAD) was the most common type of gastric cancer (GC), characterized by rapid growth and strong invasiveness.<sup>1</sup> STAD accounted for a high mortality and incidence worldwide, and approximately 70% of STAD were diagnosed

in developing countries.<sup>2</sup> Due to the lack of effective diagnosis and prognostic evaluation measures for STAD at early stage,<sup>3</sup> the prognosis of STAD was unfavorable. According to the latest report, the 5-year survival rate for STAD was estimated to be approximately 10%.<sup>4</sup> It was critical of identifying novel biomarkers for diagnosing and predicting survival of STAD patients.

Biglycan (BGN) acted as an extracellular matrix protein and played an important role in the morphology, growth, migration, and differentiation of epithelial cells.<sup>5</sup> It was found that BGN stimulated vascular endothelial growth factor (VEGF) expression in endothelial cells by activating TLR signaling pathway.<sup>6</sup> Growing evidences have confirmed the correlation of BGN with cancer progression. Aberrant expression of BGN has been reported in osteosarcoma<sup>7</sup> and ovarian cancer.<sup>8</sup> Modulation of BGN was able to influence the growth, metastasis, and angiogenesis of colon cancer,<sup>9</sup> as well as promoted the chemotherapy resistance of colon cancer by activating NF- $\kappa$ B signal transduction.<sup>10</sup> In addition, BGN could enhance the ability of migration and invasion in endometrial cancer, referring its value as a target marker for molecular therapy of advanced and recurrent endometrial cancer.<sup>11</sup> Recent studies initially indicated BGN as a core gene in STAD, and pointed out its potential significance in cancer progression. However, a deeper understanding on BGN in STAD was insufficient.

In present study, we further investigated the function of BGN in STAD. The mRNA and protein expressions of BGN in STAD were firstly investigated. Potential genetic alteration and immune infiltration analyses were also assessed. Prognostic value of BGN in STAD was subsequently predicted. Through the protein-protein interaction (PPI) network analysis on co-expressed genes with BGN, we determined the most important module containing 20 hub genes in the whole network, and the significant pathway associated with BGN involved in STAD was then predicted. Finally, related analysis on the seed gene identified from the main module was performed. This study provided a promising biomarker for STAD treatment, and was conducive to understand the pathogenesis of STAD, which can be beneficial in the improvement of life and survival of STAD patients.

## Methods

### The mRNA Expression Analysis of BGN in STAD

The gene expression profile of BGN across human tumor samples and paired normal tissues was initially explored via

Gene Expression Profiling Interactive Analysis (Gepia) database (<http://gepia.cancer-pku.cn/>) and visualized as a bar plot. The height of bar represented the median expression of certain tumor type or normal tissue. The mRNA expression distribution of BGN in cancer cell lineage was made in Cancer Cell Line Encyclopedia (CCLE) (<https://portals.broadinstitute.org/ccle/>) database. The differential expression of BGN in STAD and normal tissues was analyzed via Gepia and UALCAN (<http://ualcan.path.uab.edu/>) databases. Association between BGN expression and clinical phenotype of STAD patients was then assessed. Clinical phenotype included race, age, gender, histological subtypes, cancer stage, tumor grade, TP53 mutation status and *H. pylori* infection status.  $P < 0.05$  was regarded as the statistical significance.

### The Protein Expression of BGN in STAD

The protein expression of BGN in normal and STAD tissues was evaluated in Human Protein Atlas (HPA) database (<https://www.proteinatlas.org/>), which aimed to map all the human proteins in cells, tissues and organs. The antibody for immunohistochemistry was CAB003678, and assessment criterion contained protein staining, intensity and quantity. The protein location of BGN in a single cell was predicted via immunofluorescence with antibody of HPA003157. In addition, cell cycle dependency of BGN can also be found through HPA.

### The Genetic Alteration and Immune Infiltration Analyses

The cBioPortal database (<http://www.cbioportal.org/>) was used to explore the genetic alteration of BGN in STAD. Dataset of stomach adenocarcinoma (TCGA, Firehose Legacy) for analysis contained 369 samples with STAD, genetic alteration frequency, alteration based on detailed cancer type and mutation site can be disclosed. Furthermore, the mutation types and distribution of different types of mutations were explored through Catalogue of Somatic Mutations In Cancer (COSMIC) database (<https://cancer.sanger.ac.uk/cosmic>).

Association of BGN expression with infiltration level of immune cells was analyzed in Tumor Immune Estimation Resource (TIMER) database (<https://cistrome.shinyapps.io/timer/>). Related immune cells contained B cell, CD8+ cell, C4+ cell, neutrophil, macrophage and dendritic cell. The prognostic impact of infiltration level of immune cells on 10-years overall survival of STAD patients was also verified.

## The Prognostic Impact Analysis of BGN in STAD

The influence of BGN expression on the prognosis of STAD patients was initially evaluated through OncoLnc (<http://www.oncolnc.org/>) and Kaplan–Meier Plotter (<http://kmpplot.com/>) databases. According to the expression value of BGN, the subjects were divided into low and high expression groups. The 10-years survival of patients between low and high expression groups was then compared. A restrict survival analysis regarding BGN expression was performed based on clinical stage, TNM stage, Lauren classification, differentiation, gender, perforation, treatment and HER2 status. The potential predictive value of BGN for survival of cancer patient was assessed subsequently through Cox regression analysis in OncoLnc.  $P < 0.05$  was regarded as the statistical significance.

## Biological Function Analysis

In order to reveal the potential role of BGN in STAD, the co-expressed genes with BGN playing similar function in STAD were initially identified in cBioPortal database. All the co-expressed genes were filtered by setting the threshold of absolute correlation coefficient  $> 0.75$  and  $P < 0.001$ . A protein–protein interaction (PPI) network among these filtered genes was then constructed through String database (<https://string-db.org/>) with setting minimum required interaction score as highest confidence (0.900), and then visualized by Cytoscape. Molecular Complex Detection (MCODE) analysis in Cytoscape was subsequently conducted to determine the most important cluster in the whole network. The top 5 consistent KEGG pathways associated with hub genes in the main cluster were predicted in String, KEGG Orthology Based Annotation System (KOBAS) (<http://kobas.cbi.pku.edu.cn/>) and WEB-based Gene SeT AnaLysis Toolkit (WebGestalt) (<http://www.webgestalt.org/>) databases. In addition, a seed gene in the main MCODE cluster can be recognized and the correlation of BGN with seed gene was analyzed as well.  $P < 0.05$  was regarded as the statistical significance.

## Results

### Expression Analysis of BGN in Stomach Adenocarcinoma

Present study firstly evaluated the expression of BGN in stomach adenocarcinoma. Figure 1A indicated that BGN mRNA was over-expressed in the half of cancer types. BGN was apparently up-regulated in stomach adenocarcinoma (STAD) relative to normal tissue. Figure 1B shows its

mRNA expression in various cancer cell lines, and relative lower expression of BGN was observed in stomach cancer cell lines. Figure 1C shows the differential expression of BGN in normal and STAD tissues, confirming that BGN was highly expressed in STAD compared with normal samples (all  $P < 0.05$ ).

The association of BGN mRNA expression with clinical phenotype of STAD patients was assessed subsequently. As observed from Figure 2, lower expression of BGN was statistically observed in African-American patients and those with intestinal adenocarcinoma (Tubular). The patient's age, gender, nodal metastasis status and mutation status and H. pylori infection status did not correlate with BGN expression. The patients in stage 4 and grade 3 showed a higher expression of BGN. It followed that BGN expression was possibly correlated to the cancer progression.

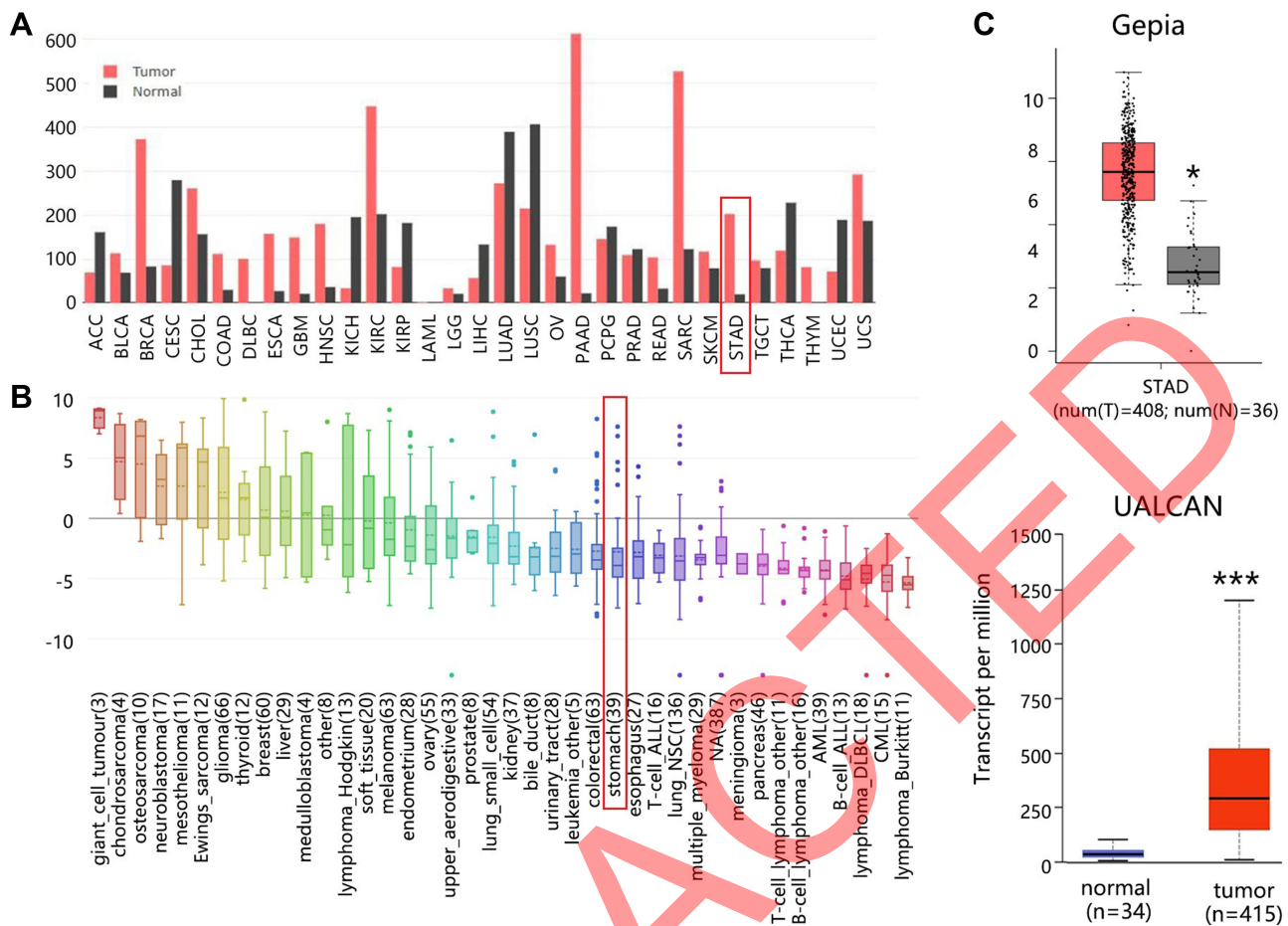
The protein expression of BGN in stomach adenocarcinoma was then assessed. Figure 3A presented that BGN protein was not detected in normal glandular cells with negative intensity. However, its protein expression in stomach tumor cells displayed an individual differences (without expression or over-expression). Figure 3B and C showed that BGN was mainly localized to the Golgi apparatus, in addition localized to the endoplasmic reticulum. We found no cell cycle dependency of BGN mRNA and protein expressions.

### Genetic Alteration and Immune Infiltration Analyses of BGN in STAD

The cBioPortal database contained 369 patients with stomach adenocarcinoma (TCGA, Firehose Legacy). Among the subjects, 5% of patients appeared genetic alteration with the main characteristics of amplification. Figure 4B displayed the alteration frequency based on the cancer type detailed. For BGN mutation, the protein change was located at W2R (Figure 4A). Detailed mutation type is presented in Figure 4C, missense (28.57%) and synonymous substitution (28.57%) were the main mutation types of BGN in stomach cancer. Observed substitution mutations were mainly presented as G>A (33.33%).

### Immune Infiltration Analysis of BGN in STAD

The correlation between infiltration level of immune cells and prognosis of STAD patients was analyzed through Timer database. Figure 5 shows that infiltration level of



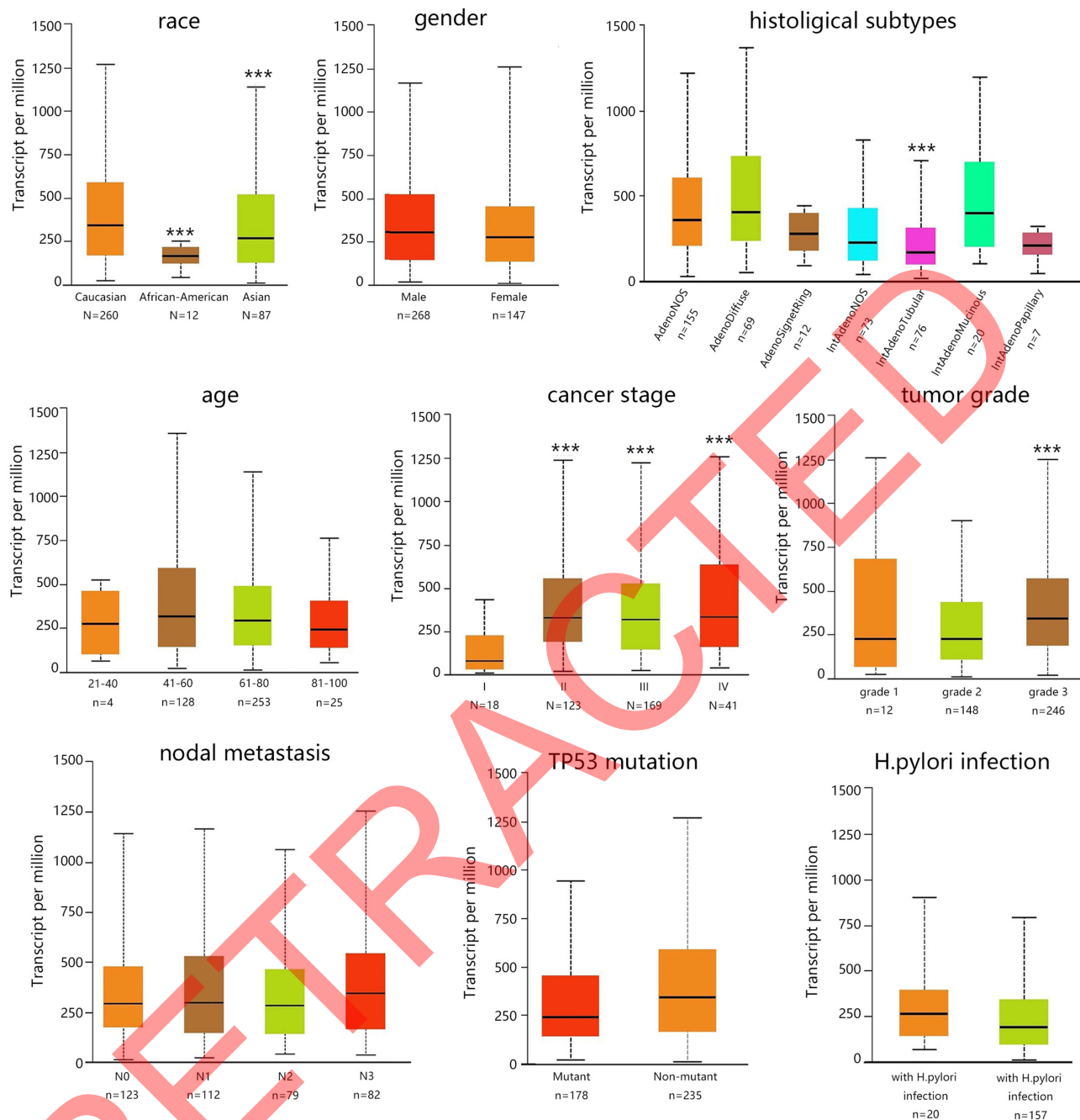
**Figure 1** The mRNA expression of BGN in STAD. **(A)** Expression profile across tumor samples and paired normal tissues. **(B)** mRNA Expression profile in cancer cell lines. **(C)** Differential expression of BGN in normal and STAD tissues. \* $P < 0.05$  and \*\*\* $P < 0.001$ . **Abbreviations:** BGN, biglycan; STAD, stomach adenocarcinoma.

macrophages correlated with the 10 years survival of patients with STAD, higher infiltration level of macrophages caused a poorer prognosis of patients ( $P = 0.004$ ). The infiltration level of other immune cells was not associated with the survival rate of patients (all  $P > 0.05$ ).

We then explored the association of BGN expression with tumor-immune system across human cancers. Regarding STAD, we observed the strongest correlation between BGN expression and lymphocyte of natural killer cell (Figure 6A,  $r = 0.578$ ,  $P < 0.001$ ), immunoinhibitor of TGFB1 (Transforming Growth Factor beta 1) (Figure 6B,  $r = 0.642$ ,  $P < 0.001$ ), immunostimulator of TNFRSF4 (TNF Receptor Superfamily Member 4) (Figure 6C,  $r = 0.377$ ,  $P < 0.001$ ), and chemokine of CXCL12 (C-X-C Motif Chemokine Ligand 12) (Figure 6D,  $r = 0.481$ ,  $P < 0.001$ ). According to the results, we speculated that lymphocyte of natural killer cell and immunostimulator of TNFRSF might make the

corresponding response to the changes of BGN over-expression, to inhibit the development of cancer. In addition, BGN might regulate the immunoinhibitor of TGFB1 and chemokine of CXCL12 in STAD, thus affecting the progression of cancer.

Transcriptomic and genomic profiling of pre-treated tumor biopsies from responders and non-responders to immunotherapy was obtained, which can be used to identify signatures and mechanisms of response to checkpoint blockade, such as anti-PDL1 and anti-PD1. Figure 7A shows that expression of BGN between responders and non-responders was different in urothelial cancer-related dataset (PMID: 29443960) with anti-PD-L1 (atezolizumab) treatment ( $P = 0.0236$ ). Mutation difference of BGN was not observed between responders and non-responders (Figure 7B, all  $P > 0.05$ ). In addition, the expression of BGN was statistically related to the immune subtypes (Figure 7C,  $P = 0.0347$ ) and molecular subtypes (Figure 7D,  $P = 0.0263$ ) in STAD.



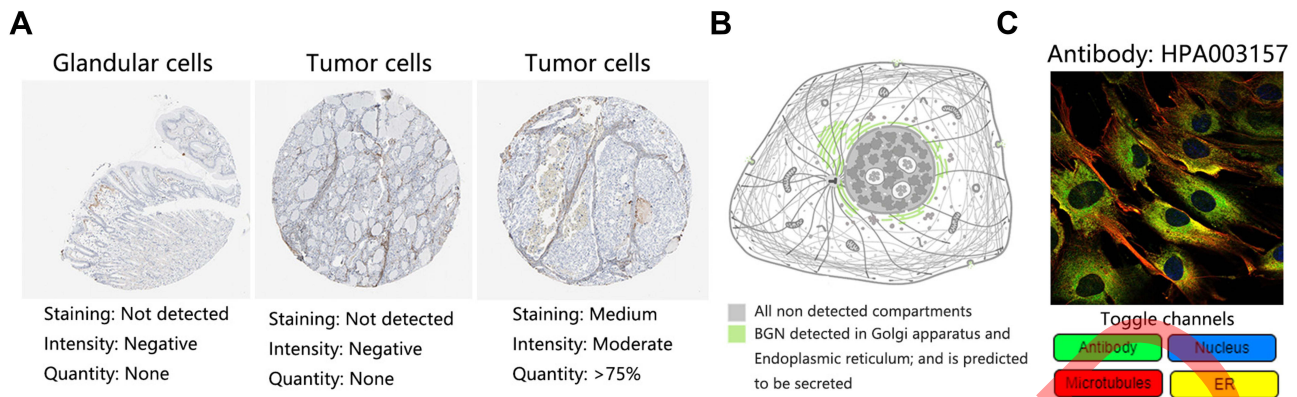
**Figure 2** The association of BGN mRNA expression with clinical phenotype of patients with STAD. \*\*\*P<0.001. **Abbreviations:** BGN, biglycan; STAD, stomach adenocarcinoma.

## Prognosis Analysis of BGN

Due to abnormal expression and mutation property of BGN in STAD, we reasonably focused on the prognostic impacts of BGN on the clinical outcome of patients. The OncoLnc database showed that BGN high expression shortens the overall survival time of patients compared with low expression group (Figure 8,  $P<0.01$ ). The survival analysis in Kaplan–Meier Plotter database ( $P<0.001$ )

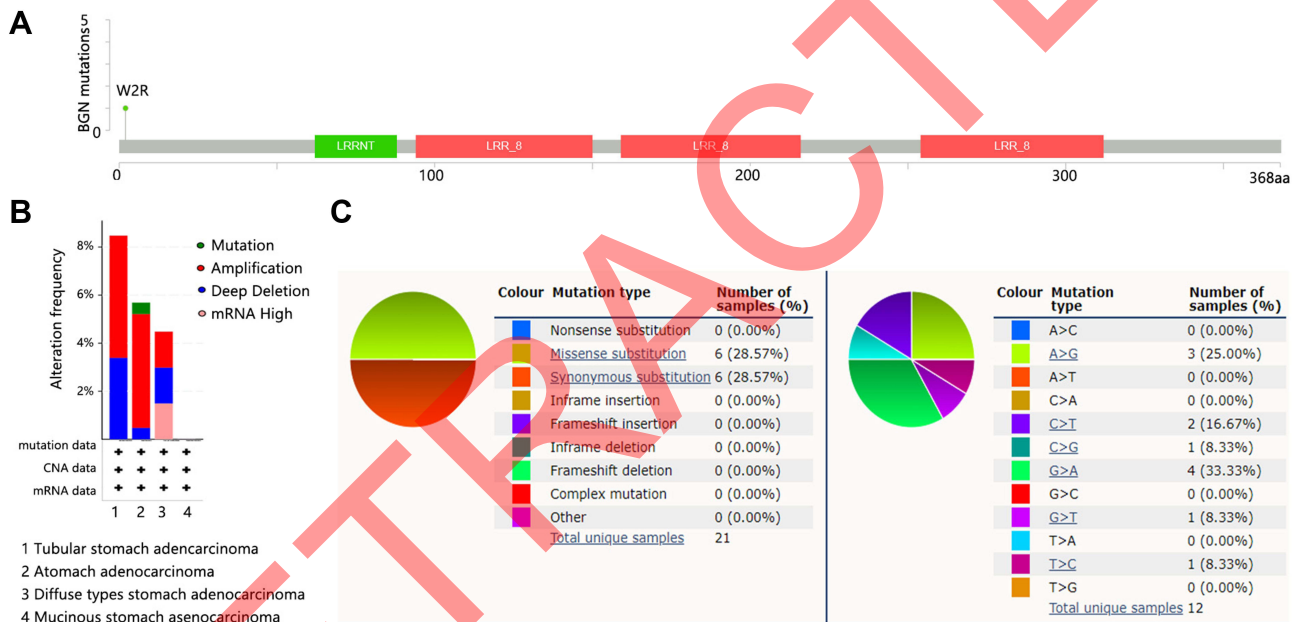
was also consistent with the result of OncoLnc. It followed that BGN high expression was not conducive to the prognosis of patients with STAD.

We further explored the detailed influence of BGN expression on the overall survival of patients. Table 1 shows that survival difference between BGN high and low expression groups appeared in patients with clinical stage 2, stage 3 and stage 4 (all  $P<0.05$ ). For stage T, only



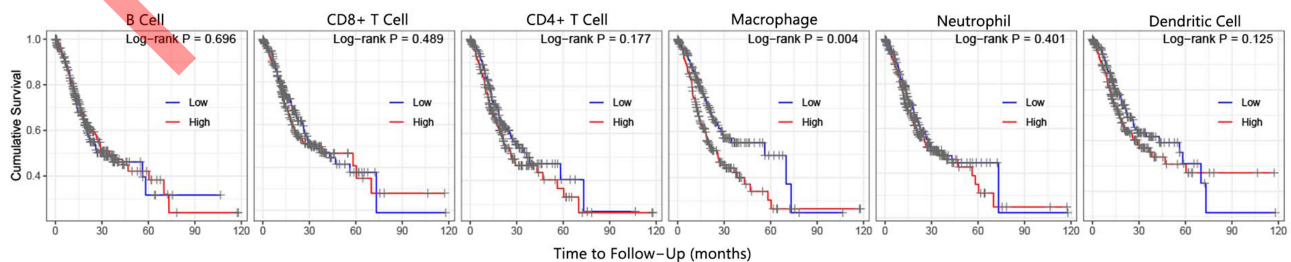
**Figure 3** The BGN protein expression. (A) Immunohistochemical images in normal and STAD tissues. (B) Protein location of BGN in cancer cell. (C) The immunofluorescence staining of BGN in cancer cell.

**Abbreviations:** BGN, biglycan; STAD, stomach adenocarcinoma.

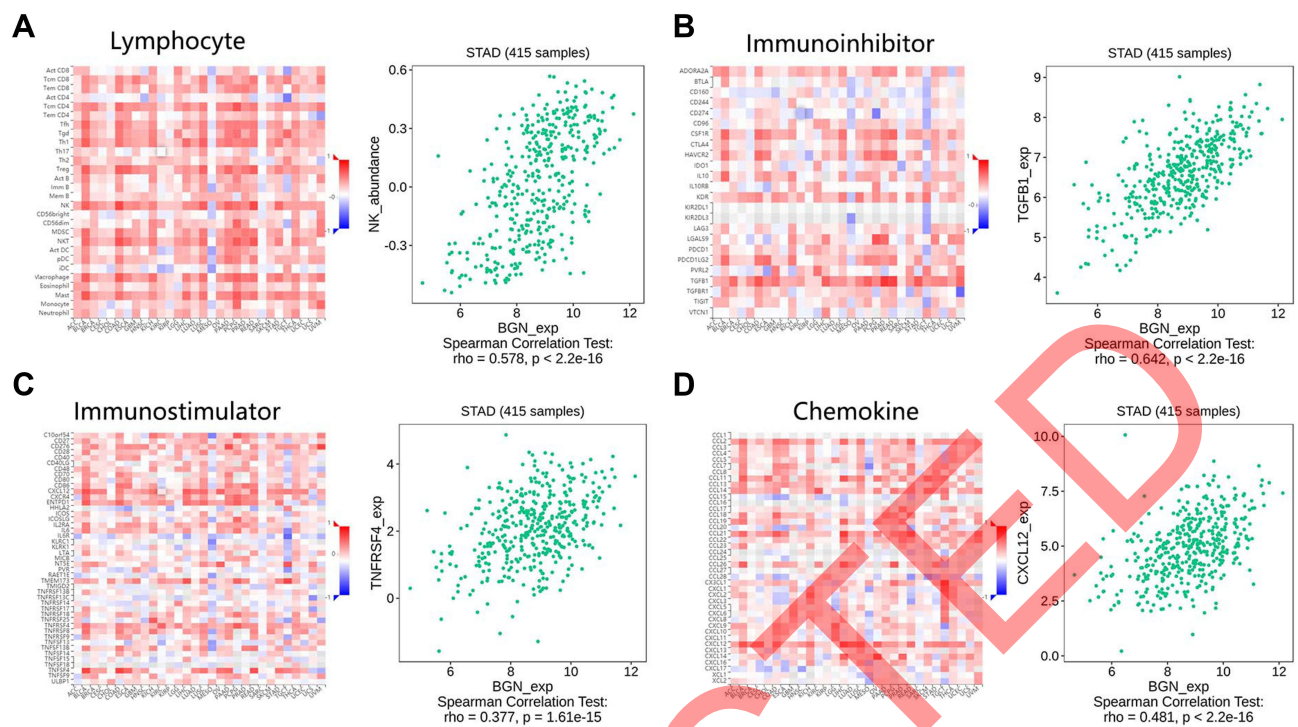


**Figure 4** The genetic alteration of BGN in STAD. (A) Mutation sites. (B) Genetic alteration based on cancer type. (C) Distribution of different types of mutations for BGN in stomach cancer.

**Abbreviation:** BGN, biglycan.



**Figure 5** Prognosis analysis on immune cells in stomach adenocarcinoma.



**Figure 6** Spearman correlations between abundance of cytokine and BGN expression in STAD. (A) Tumor-infiltrating lymphocytes. (B) Immunoinhibitor. (C) Immunostimulator. (D) Chemokine.

**Abbreviations:** BGN, iglycan; STAD, stomach adenocarcinoma.

patients in T2 showed survival difference between high and low expression groups ( $P=0.031$ ). The BGN expression also affected the prognosis of patients in N1, N2, N3 and M0 stage (all  $P<0.05$ ). In terms of Lauren classification, patients with intestinal and diffuse types displayed survival differences between high and low expression groups (all  $P<0.001$ ). Regarding differentiation of cancer, BGN expression mainly affected the survival of patients with poorly differentiated ( $P=0.036$ ). From clinical cohort perspective, the negative influence of BGN high expression on patient survival was unrestricted by gender and HER2 status (all  $P<0.001$ ). The BGN expression also influenced the survival of patients with surgery treatment alone ( $P<0.001$ ), and did not correlate with survival of patients without perforation.

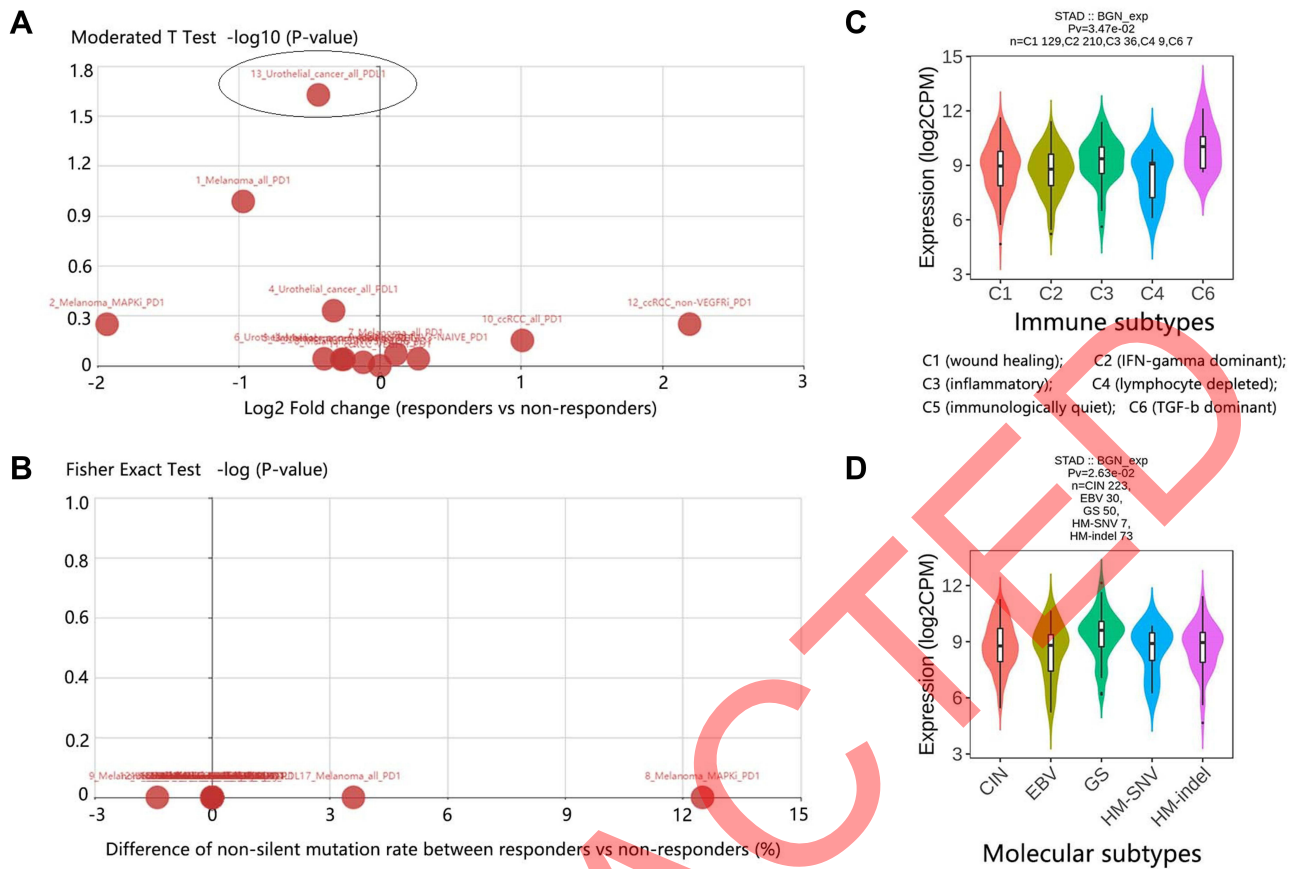
We subsequently explored the predictive value of BGN for patient survival using Cox regression. Table 2 shows that BGN can be considered as a predictor for STAD ( $P<0.05$ ). In addition, BGN was also regarded as the survival predictor of patients with BLCA (Bladder Urothelial Carcinoma), COAD (Colon adenocarcinoma), KIRP (Kidney renal papillary cell carcinoma), LGG (Brain Lower Grade Glioma) and SKCM (Skin Cutaneous Melanoma) (all  $P<0.05$ ). The Cox regression result

revealed the potential predictive value of BGN for cancer patient survival.

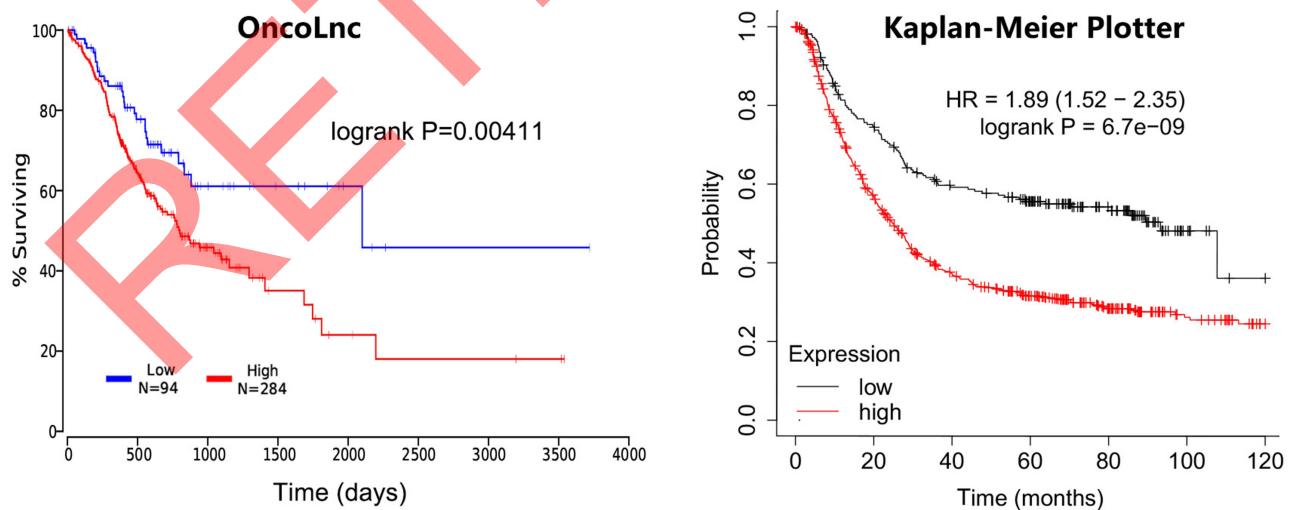
## Regulatory Network Analysis

Due to the importance of BGN expression on the patient survival, it was necessary to reveal the potential regulation associated with BGN in STAD. We firstly obtained the co-expressed genes with BGN playing a similar role in STAD through cBioPortal database. According to the threshold of absolute correlation coefficient  $>0.75$  and  $P<0.001$ , a total of 257 genes were identified. The PPI network of 257 genes was constructed through String database with setting minimum required interaction score as highest confidence (0.900). Figure 9A is visualized PPI network of String by Cytoscape, and the network contained 89 nodes and 220 edges. MCODE analysis by Cytoscape was performed to filter important clusters in the whole network. Figure 9B is the most important cluster in whole network with highest score of 9.684, comprising 20 genes and 92 edges.

Subsequently, the significant 20 genes in the main MCODE cluster were selected for the functional enrichment analysis. In this study, we used three databases to explore the potential KEGG pathways, and the top 5 consistent pathways predicted in three databases are presented at Table 3.



**Figure 7** Comparison analysis on BGN expression. **(A)** Expression difference between responders and non-responders. Points in the above scatter plot represent the expression difference of BGN in various data sets. Oval marker: dataset showing statistical significance. **(B)** Mutation difference between responders and non-responders. Points in the above scatter plot represent the mutation difference of BGN in various data sets. **(C)** Expression difference based on immune subtypes in STAD. **(D)** Expression difference based on molecular subtypes in STAD. **Abbreviations:** BGN, biglycan; STAD, stomach adenocarcinoma.



**Figure 8** The influence of BGN expression on the overall survival of patients. **Abbreviations:** HR, hazard ratio; BGN, biglycan.

**Table I** The Restrict Prognosis Analysis Between BGN High and Low Expression Groups

Characteristics			HR (95% CI)	P-value
Sub-type	Clinical stage	Stage 1	1.52 (0.43–5.39)	0.510
		Stage 2	2.24 (0.94–5.31)	0.061
		Stage 3	2.14 (1.47–3.12)	5.00E-05
		Stage 4	1.65 (1.04–2.63)	0.032
	Stage T	T1	/	/
		T2	1.83 (1.05–3.19)	0.031
		T3	1.32 (0.88–1.99)	0.180
T4		1.99 (0.66–5.98)	0.210	
Stage N	N0	1.26 (0.42–3.78)	0.680	
	N1	3.07 (1.63–5.77)	2.40E-04	
	N2	2.4 (1.32–4.38)	3.10E-03	
	N3	2.09 (1.08–4.07)	0.0260	
Stage M	M0	2.22 (1.51–3.26)	2.90E-05	
	M1	1.19 (0.6–2.35)	0.610	
Lauren classification	Intestinal	3.11 (1.94–4.98)	6.40E-07	
	Diffuse	2.15 (1.37–3.37)	6.60E-04	
	Mixed	1.38 (0.44–4.38)	0.580	
Differentiation	Poorly differentiated	1.79 (1.03–3.1)	0.036	
	Moderately differentiated	1.26 (0.6–2.63)	0.540	
	Well differentiated	2.5 (0.73–8.5)	0.130	
Clinical cohorts	Gender	Female	1.94 (1.24–3.06)	3.40E-04
		Male	1.78 (1.36–2.34)	2.30E-05
	Perforation	No	1.54 (0.94–2.53)	0.085
		Yes	/	/
Treatment	Surgery alone	1.9 (1.31–2.75)	6.20E-04	
	5 FU based adjuvant	0.91 (0.61–1.35)	0.620	
	Others adjuvant	1.98 (0.58–6.75)	0.270	
HER2 status	Negative	1.71 (1.28–2.28)	2.00E-04	
	Positive	1.97 (1.41–2.74)	4.30E-05	

**Abbreviations:** T, topography; N, lymph node; M, metastasis; HER2, human epidermal growth factor receptor-2.

The analysis showed that co-expressed genes largely participated in protein digestion and absorption, ECM–receptor interaction, focal adhesion, human papillomavirus (HPV) infection and PI3K–Akt signaling pathway (all  $P < 0.05$ ).

In the MCODE analysis, MXRA8 (matrix remodeling associated 8) was determined as the seed gene in the cluster, showing its regulatory significance. Figure 10A presents a strong correlation between BGN and MXRA8 expressions ( $\text{cor} = 0.851$ ,  $P < 0.001$ ). The expression comparison of BGN and MXRA8 is then presented at Figure 10B, and the result indicated that there was almost no expression of BGN and MXRA8 in normal tissues. In addition, BGN expression was higher in STAD than MXRA8. Figure 10C shows a poor

survival time of STAD patients with MXRA8 higher expression ( $\text{HR} = 1.90$ ,  $P < 0.001$ ).

## Discussion

Recently, biglycan (BGN) has been identified as a tumor endothelial cell marker that was associated with tumor progression in various cancers. Previous studies identified BGN as a core gene with high expression in stomach adenocarcinoma (STAD), which was associated with the survival of patients.<sup>12–14</sup> Former studies initially reported the significance of BGN in STAD, and the present study aimed to further investigate its potential role in STAD. Our study revealed the potential function of BGN from aspects

**Table 2** Cox Regression Results for BGN in Human Cancers

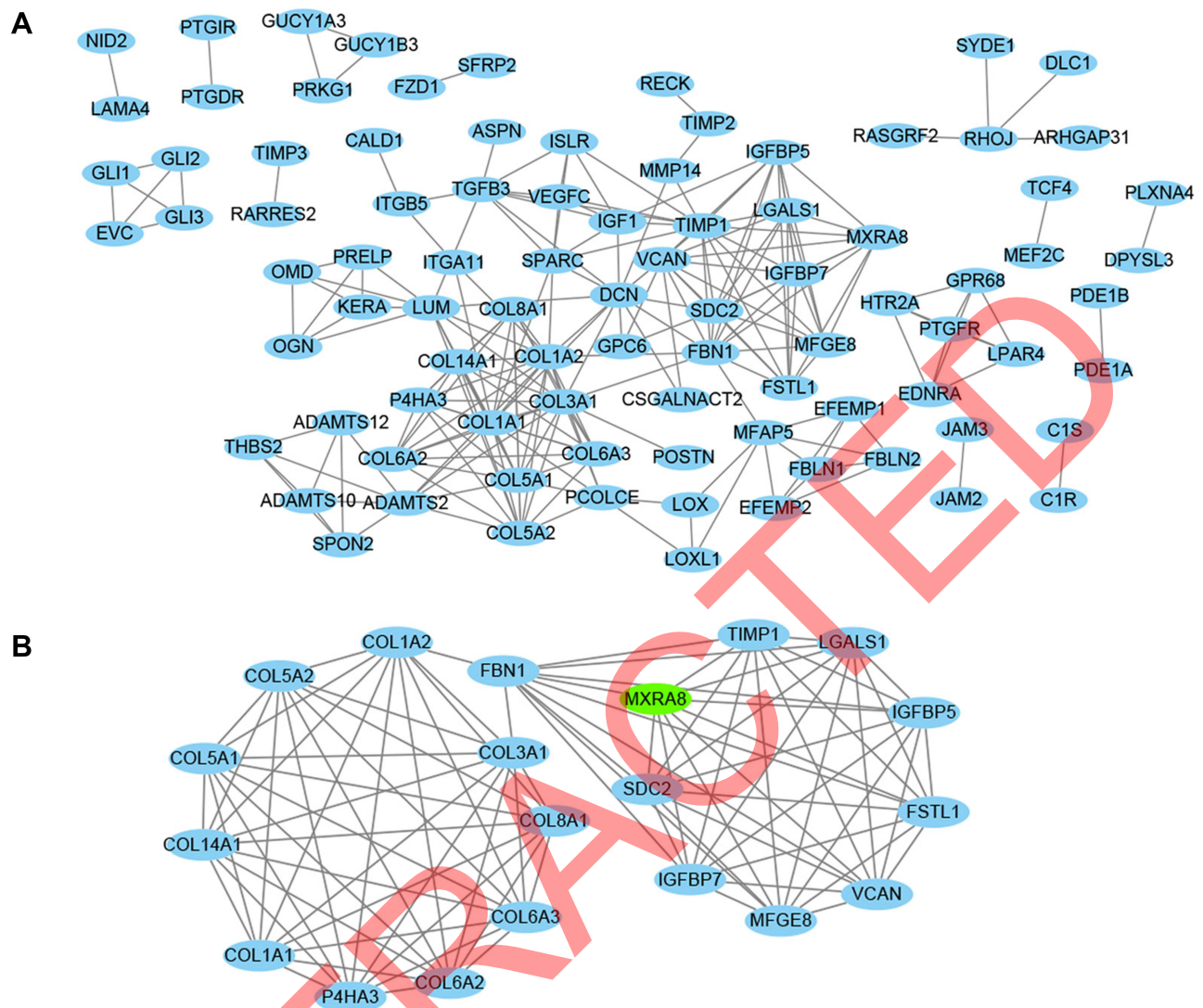
Cancer	Cox Coefficient	P-value	FDR Corrected	Median Expression
BLCA	0.173	2.80E-02	1.71E-01	4840.94
BRCA	0.029	7.50E-01	9.12E-01	13534.75
CESC	0.145	2.70E-01	6.16E-01	3519.3
COAD	0.227	2.70E-02	3.36E-01	3668.32
ESCA	0.002	9.90E-01	9.95E-01	7597.77
GBM	0.083	3.90E-01	8.97E-01	5275.09
HNSC	0.052	4.60E-01	7.59E-01	7745.8
KIRC	0.154	5.30E-02	1.15E-01	18792.74
KIRP	0.501	1.30E-03	1.21E-02	3734.77
LAML	-0.183	1.10E-01	4.86E-01	20.07
LGG	0.262	5.90E-03	1.56E-02	1158.44
LIHC	-0.047	6.20E-01	8.15E-01	3959.11
LUAD	0.067	3.60E-01	6.00E-01	11285.2
LUSC	0.084	2.00E-01	7.13E-01	8774.25
OV	0.126	1.00E-01	6.69E-01	6992.26
PAAD	-0.025	8.20E-01	9.06E-01	24473.83
READ	0.379	8.10E-02	9.32E-01	3985.44
SARC	0.022	8.30E-01	9.29E-01	19533.82
SKCM	0.144	3.20E-02	1.31E-01	4732.43
STAD	0.202	1.70E-02	2.36E-01	9300.53
UCEC	0.149	1.40E-01	9.64E-01	4548.51

of expression, genetic alteration, immune infiltration, prognostic value and significant pathway analyses.

We found the genetic alteration of BGN in STAD patients with the main characteristic of amplification. Mutation of BGN appeared as well characterized by missense substitution. Subbarayan et al found no mutations, but amplifications and deletions of BGN in breast cancer.<sup>15</sup> In this study, BGN was highly expressed in STAD, and BGN higher expression was observed in patients with stage 4 and grade 3, suggesting the association of BGN expression with cancer progression. Furthermore, BGN high expression caused a poor survival of STAD patients. Study by Schulz et al showed that up-regulation of BGN protein in bladder cancer cells predicted a poor oncological survival in the institutional cohort.<sup>16</sup> Pinto et al found the over-expression of BGN was associated with disease relapse and poor prognosis in patients with advanced cancer stages.<sup>17</sup> In addition, gastric cancer cell with BGN knock-out displayed a lower cell survival, migration, and angiogenic potential, which can be restored when gastric cancer was supplemented with exogenous BGN. More and more researches implied the BGN as a potential prognostic biomarker or therapeutic target for cancer. Zhou et al identified BGN as a fibroblast-specific biomarker of poorer prognosis of colorectal cancer.<sup>18</sup> High expression of BGN

was associated with poor disease-free survival of esophageal squamous cell carcinoma patients.<sup>19</sup> Low BGN content in preoperative serum in patients with lung cancer indicated a low malignancy.<sup>20</sup> Favorably, the significance of BGN has been revealed in a growing body of researches.

The KEGG pathway analysis further indicated that BGN possibly participated in protein digestion and absorption, ECM-receptor interaction, focal adhesion, human papillomavirus infection (HPV) and PI3K-Akt signaling pathway. Protein digestion and absorption belonged to metabolic pathway, which was correlated to the expression of metabolites.<sup>21</sup> ECM-receptor interaction, focal adhesion, and PI3K-Akt signaling pathway were the common regulatory pathways involved in cancer progression. BGN can be able to protect human neuroblastoma cells from nitric oxide-induced death by inhibiting AMPK-mTOR mediated autophagy and intracellular ROS level.<sup>22</sup> The viral infection has played a big part in the development of cancer. It has been estimated that worldwide up to 10% of all human cancers were the result of viral infection. Human papillomavirus (HPV) can induce the transformation of normal cells into cancer cells and this may be the underlying cause of carcinogenesis in many different types of cancer, such as liver cancer, gastric cancer and even



**Figure 9** Co-expressed genes analysis. (A) Whole protein-protein interaction (PPI) network. (B) MCODE network with highest score in PPI network. MXRA8: seed gene.

glioblastoma<sup>23</sup> The study indicated that prevalence was significantly higher in gastric cancer for human papillomavirus (Odds Ratio=1.63).<sup>24</sup> PI3K/Akt/mTORs signaling cascade played a very important role in HPV-induced carcinogenesis by acting through multiple cellular and molecular events, and contributed to the immortalization

and carcinogenesis of HPV-transduced cells.<sup>25</sup> However, the study did not confirm the presence or biological activity of HPV in gastric cancer, suggesting the relationship between gastric cancer and HPV infection seemed doubtful.<sup>26</sup> It followed that the role of viral infection in stomach cancer should be further discussed.

**Table 3** The Top 5 Consistent KEGG Pathways Predicted in Three Databases

Pathway ID and Name	WebGestalt (P-value)	KOBAS (Corrected P-value)	String (False Discovery Rate)
hsa04974: Protein digestion and absorption	1.91E-13	2.35E-15	5.63E-13
hsa04512: ECM-receptor interaction	6.94E-06	1.03E-6	1.21E-05
hsa04510: Focal adhesion	2.27E-04	1.78E-5	2.40E-04
hsa05165: Human papillomavirus infection	1.71E-03	6.34E-5	7.30E-04
hsa04151: PI3K-Akt signaling pathway	2.00E-03	7.12E-5	7.30E-04

**Abbreviation:** KEGG, KEGG-Kyoto Encyclopedia of Genes and Genomes.



**Figure 10** MXRA8 expression analysis. (A) Correlation of BGN with MXRA8 adjusted by tumor purity. (B) Expression comparison in normal/STAD tissues. (T: tumor; N: normal). (C) Survival analysis on MXRA8.

**Abbreviations:** BGN, biglycan; MXRA8, matrix remodeling associated 8; HR, hazard ratio.

Moreover, the regulatory network analysis in this study uncovered a significant gene of MXRA8 (matrix remodeling associated 8) closely associated with BGN. Existing research indicated that MXRA8 was a receptor for multiple alphaviruses,<sup>27</sup> and ectopic MXRA8 expression was sufficient to enhance chikungunya infection and lethality in transgenic flies, suggesting that targeting this protein may mitigate disease in humans.<sup>28</sup> There were few studies associated with MXRA8 in cancer field up to now. Our work found that MXRA8 high expression caused an unfavorable prognosis of STAD patients. Recent study also suggested that high expression of MXRA8 led to a worse overall survival of patients with kidney renal clear cell carcinoma and was significantly associated with disease-free survival.<sup>29</sup> Significance research of MXRA8 in cancer was to be continued.

Additionally, this study has certain limitations that should be acknowledged. The expression of BGN in tumor and normal tissues should be verified in clinical samples. The underlying molecular mechanisms indicated by pathway analysis have not been determined yet. Present study was conducted by pure bioinformatics, which weakens the strength of our conclusions. Further experimental research is needed to support our findings. However, our results might be valuable to clinicians and researchers, demonstrating a new biomarker for stomach adenocarcinoma, which may help develop novel early interventions in cancer treatment.

## Conclusions

In conclusion, our study showed that BGN was significantly up-regulated in STAD. Kaplan–Meier analysis showed that higher BGN expression was associated with poorer survival of STAD patients. Furthermore, we identified key pathways associated with BGN and provided more information about molecular mechanisms about

STAD progression, holding promise for acting as a biomarker and potential therapeutic target for STAD.

## Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author of Bing Chen on reasonable request.

## Disclosure

The authors have no conflicts of interest in this work.

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