<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Osteopontin as potential biomarker and therapeutic target in gastric and liver cancers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
<td>Cao, DX; Li, ZJ; Jiang, XO; Lum, YL; Khin, E; Lee, NPY; Wu, GH; Luk, JMC</td>
</tr>
<tr>
<td><strong>Citation</strong></td>
<td>World Journal Of Gastroenterology, 2012, v. 18 n. 30, p. 3923-3930</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>2012</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/180178">http://hdl.handle.net/10722/180178</a></td>
</tr>
<tr>
<td><strong>Rights</strong></td>
<td>Creative Commons: Attribution 3.0 Hong Kong License</td>
</tr>
</tbody>
</table>
Osteopontin as potential biomarker and therapeutic target in gastric and liver cancers

Dong-Xing Cao, Zhi-Jie Li, Xiao-Ou Jiang, Yick Liang Lum, Ester Khin, Nikki P Lee, Guo-Hao Wu, John M Luk

Abstract

Gastric cancer and liver cancer are among the most common malignancies and the leading causes of death worldwide, due to late detection and high recurrence rates. Today, these cancers have a heavy socioeconomic burden, for which a full understanding of their pathophysiological features is warranted to search for promising biomarkers and therapeutic targets. Osteopontin (OPN) is overexpressed in most patients with gastric and liver cancers. Over the past decade, emerging evidence has revealed a correlation of OPN level and clinicopathological features and prognosis in gastric and liver cancers, indicating its potential as an independent prognostic indicator in such patients. Functional studies have verified the potential of OPN knockdown as a therapeutic approach in vitro and in vivo. Furthermore, OPN mediates multifaceted roles in the interaction between cancer cells and the tumor microenvironment, in which many details need further exploration. OPN signaling results in various functions, including prevention of apoptosis, modulation of angiogenesis, malfunction of tumor-associated macrophages, degradation of extracellular matrix, activation of phosphoinositide 3-kinase-Akt and nuclear factor-κB pathways, which lead to tumor formation and progression, particularly in gastric and liver cancers. This editorial aims to review recent findings on alteration in OPN expression and its clinicopathological associations with tumor progression, its potential as a therapeutic target, and putative mechanisms in gastric and liver cancers. Better understanding of the implications of OPN in tumorigenesis might facilitate development of therapeutic regimens to benefit patients with these deadly malignancies.

© 2012 Baishideng. All rights reserved.

Key words: Osteopontin; Gastrointestinal cancer; Metastasis; Prognosis; Biomarker

Peer reviewers: Dr. Fernando J Corrales, Division of Hepatology and Gene Therapy, Center for Applied Medical Research, University of Navarra, Av. Pio XII 55, 31008 Pamplona, Spain; Wei Jia, Professor, Nutrition Unit, University of North Carolina at Greensboro, 500 Laureate Way, Suite 4226, Greensboro, KA 28081, United States


INTRODUCTION

Gastric and liver cancers are among the most common malignancies and leading causes of death worldwide,
which carries a heavy socioeconomic burden. Until now, surgical resection has remained the frontline treatment for patients with early stage gastric and liver cancers. Nevertheless, the majority of such patients have poor prognosis due to high rates of tumor recurrence as well as lymph node (LN) and systemic metastases. Therefore, a full understanding of gastric and liver cancers is crucial to develop useful prognostic markers and therapeutic targets.

During the past decade, emerging evidence has refined the value of osteopontin (OPN) as a candidate biomarker and target for cancer therapy[1]. OPN is a secretory extracellular matrix (ECM) protein that is involved in a series of physiological and pathophysiological processes including but not limited to cell attachment, migration, invasion, proliferation, tissue remodeling, bone formation and even inflammation[1-4]. OPN is frequently overexpressed in human cancers and contributes to tumor formation and progression[5,6]. OPN belongs to the small integrin binding ligand N-linked glycoprotein family, which consists of members serving as markers of early cancer progression, due to their capabilities in modulating the activity of matrix metalloproteinases (MMPs)[7]. OPN participates in the interactions between cancer cells and tumor stroma, which plays a pivotal role in malignant cancer phenotype. A more thorough understanding of the functional role of OPN in the tumor microenvironment is warranted. There have been many reports on OPN and gastric and liver cancers, therefore, this review aims to summarize recent findings on clinical implications of OPN, its potential as a therapeutic target, and its related mechanisms in these two types of cancer. Further understanding on the role of OPN in gastric and liver cancers may facilitate development of therapeutic strategies in such patients.

**OPN GENE AND PROTEIN STRUCTURE**

OPN is a matrix glycoprotein secreted by a variety of cell types including osteoclasts, endothelial cells, epithelial cells, and activated immune cells such as macrophages and T cells[8]. It is also known as bone sialoprotein I, early T lymphocyte activation 1 and secreted phosphoprotein 1[9-11]. Human OPN gene is located on chromosome 4q21-q25, spans approximately 11 kb, and consists of seven exons encoding the OPN protein with 314 amino acid residues[12]. It contains several highly conserved structural elements, including arginine-glycine-aspartate and Ser-Val-Val-Tyr-Gly-Leu-Arg domains for integrin binding, a calcium binding site and a heparin binding domain for CD44 receptor binding[13] (Figure 1). Alternative splicing produces three OPN isoforms, OPN-a, OPN-b and OPN-c, which probably display different expression profiles and functional heterogeneity in a tumor-specific manner[14,15]. Moreover, OPN protein is subjected to a series of post-translational modifications including serine/threonine phosphorylation, glycosylation and tyrosine sulfation, resulting in molecular variants ranging from 25 to 75 kDa[16]. These modifications are cell type specific and depend on physiological and pathophysiological factors, which likely affect both OPN structure and functions[17].

**OPN OVEREXPRESSION AND CLINICAL VALUE IN PATIENTS WITH GASTRIC CANCER**

OPN expression is significantly elevated in most gastric cancer patients at both transcriptional and translational levels[18,24]. OPN protein is overexpressed in both primary gastric cancer and metastatic lesions, mildly expressed in the epithelial cells in chronic atrophic gastritis that is a precancerous lesion for gastric cancer, and negatively in normal gastric mucosa, which indicates that OPN may play a role and serve as a potential biomarker in the formation and progression of gastric cancer[19-28]. Moreover, Wu et al[29] have found higher OPN plasma level in gastric cancer patients as compared with healthy individuals, suggesting that OPN plasma level may also be a biomarker for gastric cancer, and is of particular clinical interest because plasma-derived biomarkers are more convenient in clinical application than biomarkers from tissues. In gastric cancer tissues, OPN protein is diffusely located in the cytoplasm of tumor cells as well as tumor-associated macrophages (TAMs), which is in line with its implications in the interactions between cancer cells and tumor stroma.

Until now, the diagnostic and prognostic values of OPN have been implicated in gastric cancer patients. Microarray studies have identified gene signatures including OPN in gastric cancer patients[18]. OPN overexpression is significantly associated with clinicopathological parameters in gastric cancer such as low apoptotic index, high proliferative index, low grade, high stage, LN and vascular invasion, and distant metastasis[20-24]. In addition, OPN overexpression is an independent predictor of poor prognosis and tumor recurrence in patients with gastric cancer[21-23]. Dai et al[22] have suggested that patients with OPN-positive gastric cancer have poorer outcome than OPN-negative cases. Multivariate analysis has revealed OPN expression as an independent prognostic indicator of poor disease-free and overall survival in patients with gastric cancer, particularly for survival in cases in tumor node, metastasis (TNM) stage II and III. The prognostic value of the marker combinations of OPN with conventional biomarkers has also been explored in gastric cancer patients. Zhang et al[26] have found the combination of OPN and caudal-related homeobox gene 2 (CDX2) as a survival predictor of advanced gastric cancer patients. OPN plasma level is commonly elevated in patients with gastric cancer, and is significantly associated with the clinicopathological features including late stage, serosal invasion, LN and vascular invasion, and liver metastasis[19]. High OPN plasma level is inversely correlated with poor prognosis in gastric cancer patients, especially in those with invasive phenotypes. Thus, elevated OPN plasma level may serve as an independent risk factor for poor survival in gastric cancer patients.
**OPN OVEREXPRESSION AND CLINICAL VALUE IN PATIENTS WITH LIVER CANCER**

OPN is positive in most hepatocellular carcinoma (HCC) patients at both transcriptional and translational levels\(^{[25-30]}\). Yuan et al\(^{[28]}\) demonstrated OPN mRNA overexpression in 79 (51%) of 156 primary HCC patients. Kim et al\(^{[35]}\) disclosed that OPN protein was expressed in 92 (32.3%) of 285 tumors. The expressions of OPN mRNA and protein display a positive correlation\(^{[39]}\). In HCC, OPN is secreted by both cancer cells and TAMs, and secreted by bile duct epithelium and stellate cells, but not by normal hepatocytes or Kupffer cells, in normal liver conditions\(^{[34,38]}\). OPN\(^+\) cancer cells are often dispersed in the periphery of cancer nodules and are adjacent to stromal cells\(^{[30,33]}\). In addition, OPN plasma level is also significantly elevated in HCC patients, especially in those with cirrhosis or in advanced stages\(^{[30-32]}\). Kim et al\(^{[30]}\) determined that OPN plasma level in HCC patients was significantly higher than in patients with chronic liver diseases or healthy controls (954 ng/mL vs 381 ng/mL; 954 ng/mL vs 155 ng/mL). Zhang et al\(^{[44]}\) also found that OPN plasma level of HCC patients was significantly higher than that of healthy controls (176.90 ng/mL vs 63.74 ng/mL). These data propose that elevated OPN plasma level can serve as a potential biomarker for HCC.

Meanwhile, several microarray studies have identified OPN-containing gene signatures of HCC patients\(^{[30,33]}\). Ye et al\(^{[31]}\) have identified OPN as a leading gene in the gene signature that was relevant to tumor metastasis and patient survival. Luo et al\(^{[33]}\) have found that overexpressed OPN gene belongs to a specific gene signature in HCC. In addition, many studies have established a significant correlation between OPN overexpression and clinicopathological features of HCC, including the severity of liver damage according to Child-Pugh class, high grade, late stage, LN/vascular/bile duct/capsular invasion, and intrahepatic or distant metastases\(^{[30,33,40,44]}\). Until now, OPN overexpression has been revealed as an independent prognostic factor for poor overall and disease-free survival in HCC patients\(^{[25-28,33,42,47]}\). In 2010, Weber et al\(^{[43]}\) performed a meta-analysis and found that OPN level correlated with poor overall and disease-/relapse-free survival, and as a biomarker for stage, grade, and early tumor progression in HCC. Chen et al\(^{[45]}\) disclosed that OPN expression was a prognostic marker for HCC patients at TNM stage I. Furthermore, novel biomarker combinations are evaluated to predict patient outcome in HCC, since classical parameters cannot provide exact information. The biomarker combinations, OPN and \(\alpha\)-fetoprotein (AFP), or OPN and CD44s, are revealed to have better prognostic value than the classical diagnostic biomarkers\(^{[35,46]}\). Huang et al\(^{[49]}\) have suggested that the combination of OPN and caspase-3 can be an effective indicator for HCC patients after curative resection. However, because the published data are conflicting in many cases, further large-scale studies are necessary to confirm their clinical value\(^{[49]}\).

Tumor recurrence is a persistent issue after surgical resection. A number of studies have suggested OPN as a useful marker for predicting early recurrence in HCC patients\(^{[25-27,33,44-46,50]}\). OPN polymorphisms and the combination of OPN and CD44 are potential predictors of tumor recurrence in HCC\(^{[45,46]}\). OPN overexpression is associated with early recurrence of hepatitis C virus (HCV)-related HCC\(^{[50]}\). Chen et al\(^{[45]}\) found that OPN expression was correlated with early postoperative recurrence in patients at stage I. Sieghart et al\(^{[51]}\) have revealed that OPN is an independent predictor of tumor recurrence and survival in HCC patients beyond Milan criteria undergoing orthotopic liver transplantation. Thus, OPN may be able to help determine the patients who need adjuvant therapy to prevent early recurrence after surgical resection.

At present, many serum biomarkers are under evaluation for the detection of HCC, but none of them has sufficient sensitivity and specificity to be considered in the guidelines. OPN plasma level increases significantly with advanced Child-Pugh class, large tumor size, high grade, and late stage\(^{[33,48]}\). OPN plasma level is suggested as an adverse prognostic factor for both overall survival, disease-free survival and relapse-free survival in hepatitis...
Table 1 Osteopontin as a potential therapeutic target for gastric and liver cancers

<table>
<thead>
<tr>
<th>Cell lines</th>
<th>Mouse model</th>
<th>Method of study</th>
<th>Resultant effects</th>
<th>Possible mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric cancer</td>
<td>SGC7901</td>
<td>Nude mice</td>
<td>siRNA knockdown</td>
<td>Reduced angiogenesis in vitro and in vivo</td>
</tr>
<tr>
<td>BGC-823</td>
<td>Nude mice</td>
<td>Transient/stable siRNA knockdown</td>
<td>Inhibited cell growth, anchorage-independent growth, migration and invasion in vitro, and suppressed tumor growth and prolonged survival in vivo</td>
<td>Inhibition of MMP-2 and uPA expression, NF-κB DNA binding activity, and Akt phosphorylation</td>
</tr>
<tr>
<td>SGC7901</td>
<td>Nude mice implanted with SGC-OPN-cells</td>
<td>Lentivirus-mediated stable depletion</td>
<td>Suppressed metastases and prolonged survival time in vivo</td>
<td>Reducing expression of VEGF</td>
</tr>
<tr>
<td>HCC-LM6</td>
<td>Nude mice implanted with HCC-LM6</td>
<td>Antisense knockdown</td>
<td>Suppressed migration and invasion in vitro, decreased lung metastases in vivo</td>
<td>Inhibiting MMP-2 and uPA expression</td>
</tr>
<tr>
<td>HCC-LM3</td>
<td>Nude mice implanted with Lentiv OPNi-transfected HCC-LM3 cells</td>
<td>Stable depletion using lentiviral vectors encoding miRNA against OPN</td>
<td>Inhibited both in vitro proliferation, invasion and in vivo tumor growth and lung metastasis</td>
<td>Inhibiting MAPK and NF-κB pathways, and MMP-2 and suppressing uPA expression</td>
</tr>
<tr>
<td>HCC-LM3 HepG2</td>
<td>Nude mice</td>
<td>shRNA gene silencing</td>
<td>Inhibited HCC cell growth, adhesion and invasion in vitro, and suppressed tumorigenecity and lung metastasis in vivo, enhanced sensitivity of HCC cells to chemotherapeutic drugs</td>
<td>Suppressing αv, β1, β3 integrin expression, blocking NF-κB activation, inhibiting apoptosis</td>
</tr>
</tbody>
</table>

HCC: Hepatocellular carcinoma; OPN: Osteopontin; siRNA: Small interfering RNA; MAPK: Mitogen-activated protein kinase; NF: Nuclear factor; MMP: Matrix metalloproteinase; VEGF: Vascular endothelial growth factor; uPA: Urokinase-type plasminogen activator; shRNA: Short hairpin RNA; Akt: Protein kinase B; miRNA: microRNA.

B virus (HBV)- or HCV-related HCC patients\[36,38,51\]. In addition, OPN plasma level may be a potential diagnostic biomarker for HCC in the surveillance of patients with HBV or HCV infection. Sun et al.\[51\] have suggested that preoperative plasma level of OPN and AFP can be used as a prognostic marker for early stage HCC. A recent study conducted by Shang et al.\[52\] has also identified serum OPN as a novel marker for early HCC diagnosis because OPN was found clearly elevated 1 year before diagnosis in a pilot prospective study including 22 patients. In another two studies, a greater area under curve value of OPN than AFP was observed, suggesting superior diagnostic accuracy of OPN for HCC\[38\]. HCC patients whose pretreatment OPN serum level is low and declines following transarterial chemoembolization exhibit better tumor response and longer survival\[38\]. These data suggest that OPN plasma level can be used, either independently or coupled with AFP, for predicting clinical outcome in HCC patients.

**OPN AS A POTENTIAL THERAPEUTIC TARGET FOR GaSTRIC AND LIVER CANCERS**

OPN as a therapeutic target has been explored in various cancers including cancers of breast, lung, head and neck, stomach, colon and liver. Promising results have been achieved in a series of studies\[33-37\]. The strategies often utilize OPN antibody to block its binding to receptors so as to inhibit the downstream signal transduction related to tumor growth and invasion, and deliver the small interfering RNA (siRNA) targeting OPN to tumor cells to decrease directly the expression of OPN to abrogate the effects triggered by elevated OPN.

At present, OPN-knockdown-induced tumor suppression in gastric cancer has been shown through RNA interference (RNAi)\[38-40\]. In vitro and in vivo studies have demonstrated OPN-RNAi-induced inhibition of tumor growth, migration and invasion in gastric cancer\[38,39\]. Moreover, Wang et al.\[40\] silenced OPN expression in gastric cancer cell line SGC7901 using lentiviral-OPN siRNA technology, and found reduced detectable tumors, fewer metastases, and longer survival time in mice implanted with OPN-SGC7901 cells. These data suggest that targeting OPN and its related signaling network is likely to provide an effective therapeutic approach for gastric cancer (Table 1).

In recent years, efforts have also been made to inhibit HCC progression and metastasis by interfering OPN\[37,38,61-63\]. OPN knockdown significantly suppresses migration and invasion of HCC cells in vitro and decreases lung metastases in vivo, which is associated with decreased angiogenesis in HCC cells\[61,62\]. Besides, OPN-specific antibody can effectively block HCC cell invasion in vitro and inhibit lung metastasis of HCC cells in vivo\[38\]. In addition, Zhao et al.\[39\] have demonstrated that short hairpin RNA-mediated OPN depletion enhances sensitivity of HCC cells...
Figure 2 Molecular mechanisms of osteopontin in gastrointestinal cancers. Osteopontin (OPN) signaling leads to gastrointestinal cancer growth and metastasis through activation of various pathways, including cell survival and proliferation, angiogenesis, and extracellular matrix (ECM) degradation. VEGF: vascular endothelial growth factor; PI3-K: Phosphoinositide 3-kinase; COX-2: Cyclooxygenase-2; MAPK: Mitogen-activated protein kinase; NF: Nuclear factor; uPA: Urokinase-type plasminogen activator; MMP: Matrix metalloproteinase; ERM: Ezrin/radixin/moesin; Akt: Protein kinase B.

MOLeCULaR MeChaNISMS OF OPN IN GASTRIC AND LIVER CANCERS

The multifunction of OPN has been revealed in promoting tumor formation and progression (Figure 2). It exerts these functions through direct binding to integrin and/or CD44. The subsequent activation of various pathways leads to increased malignant phenotype. Various signaling transduction pathways triggered by OPN molecule have been reported in different cancer models such as breast cancer, melanoma, lung cancer, myeloma, prostate cancer and gastrointestinal cancers. The results indicated that OPN exerts the tumor-related functions through a complicated signaling network. Here, we only summarize the reported signaling pathways of OPN relevant to gastric and liver cancers; some of which are commonly overlapped with other cancers, but some are specific in these two types of cancers. It has been suggested that phosphoinositide 3-kinase (PI3-K)/protein kinase B (Akt) pathway and hypoxia-inducible factor-1 are involved in the tumor-promoting function of OPN, which induces pro-survival and anti-apoptosis signaling in gastric and liver cancers after the survival pathway is activated. Mitogen-activated protein kinase pathway (MEK/ERK1/2) can also be triggered by OPN protein in liver cancer to promote tumor growth and metastasis, while the effect can be reversed through OPN knockdown. The NF-κB pathway is crucial to keep cell survival through initiating the gene expression of anti-apoptotic proteins, and is often induced by chemotherapeutic drugs and contributes to resistance to chemotherapy.

Several mechanisms regulating OPN gene expression have been revealed, but many details remain to be elucidated. OPN is a transcriptional target of aberrant Wnt/β-catenin signaling, and is also regulated by other molecules including specificity protein 1, v-ets erythroblastosis virus E26 oncogene homolog 1, runt-related transcription factor 2, v-myb myeloblastosis viral oncogene homolog, CDX2, deleted in liver cancer 1, late SV40 factor (LSF), epidermal growth factor (EGF), NR4A2 and NO. Interestingly, the activation of several downstream targets of OPN, such as Akt, LSF, NO, EGF and thrombin, can enhance OPN expression in turn, suggesting a positive feedback regulation of OPN gene expression. The modulation of OPN mRNA stability also influences OPN expression in HCC. In addition, miRNA-181a decreased OPN expression in HCC cell lines, suggesting that miRNA is involved in the regulation of OPN gene expression. Furthermore, the expression of OPN is also affected by COX-2 and 30-kDa Tat-interacting protein.

In short, OPN signaling could result in the activation of anti-apoptosis and pro-survival pathways via PI3-K-Akt and NF-κB signaling molecules, angiogenesis modulation via VEGF induction, ECM degradation via MMPs
and uPA secretion, leading to tumor growth and metastasis in gastric and liver cancers.

**CONCLUSION**

OPN overexpression occurs frequently in patients with gastric cancer and liver cancer. Previous studies have revealed its clinicopathological correlation with tumor formation and progression in these two types of cancer, indicating its potential as a diagnostic marker. Functional studies have shown the potential of OPN as a therapeutic target in gastric and liver cancers both in vitro and in vivo. OPN mediates multifaceted roles in the interaction between cancer cells and tumor microenvironment, in which many details need to be further explored. The various mechanisms of OPN signaling in gastric and liver cancers including evasion of apoptosis, modulation of angiogenesis, ECM degradation, activation of PI3K-Akt and NF-κB pathways, might induce the development and progression of gastric and liver cancers. However, no clinical trial targeting OPN is in progress for tumor treatment, although the importance of OPN has been widely investigated and demonstrated in various cancers, and many patents including antibodies or peptides against OPN have been filed to treat different tumors. OPN is an important cytokine to mediate normal physiological functions. Blocking OPN possibly results in severe adverse effects due to interference with normal OPN roles. Therefore, further understanding of the implications and roles of OPN in various tumors including gastric and liver cancers could help develop better therapeutic strategies for such patients. On the other hand, OPN as a secreted plasma protein seems to have a greater potential to be utilized as a diagnostic or prognostic marker for relevant cancers in combination with other biomarkers or alone.

**REFERENCES**

2. El-Tanani MK. Role of osteopontin in cellular signaling and metastatic phenotype. *Front Biosci* 2008; 13: 4276-4284
25. Chen RX, Xia YH, Cui JF, Xue TC, Ye SL. Osteopontin, a single marker for predicting the prognosis of patients with tumor-node-metastasis stage I hepatocellular carcinoma after surgical resection. *J Gastroenterol Hepatol* 2010; 25: 1435-1442


El-Din Bessa SS, Elwan NM, Suliman GA, El-Shourbagy SH. Clinical significance of plasma osteopontin level in Egyptian patients with hepatitis C virus-related hepatocellular carcinoma. Arch Med Res 2010; 41: 541-547


Wu JC, Sun BS, Ren N, Ye QH, Qin LX. Genomic aberrations in hepatocellular carcinoma related to osteopontin expression detected by array-CGH. J Cancer Res Clin Oncol 2010; 136: 595-601


Weber GF, Lett GS, Haubelin NC. Osteopontin is a marker for cancer aggressiveness and patient survival. Br J Cancer 2010; 103: 861-869


Huang H, Zhang XF, Zhou HJ, Xue YH, Dong QZ, Ye QH, Qin LX. Expression and prognostic significance of osteopontin and caspase-3 in hepatocellular carcinoma patients after curative resection. Cancer Sci 2010; 101: 1314-1319


Chen RX, Xia YH, Xue TC, Zhang H, Ye SL. Down-regulation of osteopontin inhibits metastasis of hepatocellular carcinoma cells via a mechanism involving MMP-2 and uPA. *Oncol Rep* 2011; 25: 803-808


Guo H, Marroquin CE, Wai PY, Kuo PC. Nitric oxide-depen-