Angiogenesis in gastrointestinal stromal tumors: From bench to bedside

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Abstract

Gastrointestinal stromal tumors (GISTs) are rare neoplasms with an estimated incidence from 0.78 to 1-1.5 patients per 100,000. They most commonly occur in the elderly during the eighth decade of life affecting predominantly the stomach, but also the small intestine, the omentum, mesentery and rectosigmoid. The available treatments for GIST are associated with a significant rate of recurrent disease and adverse events. Thorough understanding of GIST’s pathophysiology and translation of this knowledge into novel regimens or drug repurposing is essential to counter this challenge. The present review summarizes the existing evidence about the role of angiogenesis in GIST’s development and progression and discusses its clinical underpinnings.

Key Words: Gastrointestinal stromal tumor; Cancer; Oncology; Angiogenesis; Gastrointestinal oncology; Stromal tumors
Core Tip: Thorough understanding of gastrointestinal stromal tumors (GISTs)’s pathophysiology and translation of this knowledge into novel regimens or drug repurposing is essential to counter this challenge. The present review summarizes the existing evidence about the role of angiogenesis in GIST’s development and progression and discusses its clinical underpinnings.

Citation: Papadakos SP, Tsagkaris C, Papadakis M, Papazoglou AS, Moysidis DV, Zografos CG, Theocharis S. Angiogenesis in gastrointestinal stromal tumors: From bench to bedside. World J Gastrointest Oncol 2022; 14(8): 1469-1477
URL: https://www.wjgnet.com/1948-5204/full/v14/i8/1469.htm
DOI: https://dx.doi.org/10.4251/wjgo.v14.i8.1469

INTRODUCTION

Gastrointestinal stromal tumors (GISTs) are rare neoplasms with an estimated incidence from 0.78 patients to 2 patients per 100000[1,2]. Their highest prevalence is noted during the eight decade of age, when they affect up to 3.06 individuals per 100000[3]. GIST typically present as subepithelial masses mainly in stomach (60%) and small intestine (20%-30%) with omentum, mesentery and rectosigmoid areas being less-frequently involved areas[4]. According to their primary location, GISTs could clinically present as gastrointestinal hemorrhage, anemia, dyspepsia or constipation while extra-intestinal metastases to lymph nodes (LN) and lungs are infrequent[4]. The pathological diagnosis relies on the tissue’s morphological and molecular characteristics. Based on their morphology, GISTs are classified into three groups according to the predominant cell type: Spindle cell type (70%), epithelioid cell type (20%) and a mixed type (10%). CD117 comprises a transmembrane protein which is the end-product of the c-kit expression[6]. The KIT (CD117) positivity in immunohistochemistry (IHC) in tissues which are morphologically consistent with GIST establishes the diagnosis in the 95% of the cases. In KIT negative cases, the discovered on GIST 1 (DOG1) and CD34, which is an antigen of the myeloid progenitor cells, staining or the documentation of KIT or platelet-derived growth factor receptor (PDGFR) gene mutations are sufficient to institute a diagnosis. Seldom in pediatric and young populations, GIST formation arises in the context of succinate dehydrogenase-deficiency in conjunction with paragangliomas and pulmonary chondromas[7,8].

The pharmacologic targeting of angiogenesis in cancer therapeutics was introduced as a groundbreaking approach. Nevertheless, the anti-vascular endothelial growth factor (VEGF) targeting alone or in conjunction with chemotherapy displayed only modest benefit in overall survival in solid tumors indicating the complexity of the mechanisms that regulate tumor angiogenesis[9]. Thus, the necessity arose to develop a broad spectrum of anti-angiogenetic treatments such as: Direct VEGFR2 antagonists (ramucirumab), VEGF-Traps (aflibercept), several receptor tyrosine kinases inhibitors targeting the PDGF-R, CD117 (c-KIT), fibroblast growth factor receptors (FGFR), epidermal growth factor receptor, RET, RAF kinases and the repurposing of drugs like the mammalian target of rapamycin inhibitors and lenalidomide[9,10]. In fact, anti-angiogenetic therapy has gained ground in the management of advanced, unresectable disease. Imatinib, an abl, c-KIT and PDGF-R tyrosine kinase inhibitor (TKI), constitutes the empiric treatment when the mutational status of the disease remains unknown and the first line of treatment in KIT and PDGFR positive metastatic, inoperable GISTs. The D842V mutation in PDGFRα comprises a therapeutic exception and is being treated with avapritinib while KIT and PDGFR wild type tumors are treated with sunitinib or regorafenib[11].

All the above mentioned drugs achieve, at least partially, their cytotoxicity disrupting signaling pathways which are implicated in angiogenesis, as it would be further analyzed below. This suggests that angiogenesis might be of paramount importance for the carcinogenesis process in GISTs and an attempt to summarize all the pre-clinical and clinical data would be of great value.

THE ROLE OF ANGIOGENESIS IN GIST’S DEVELOPMENT AND PROGRESSION

The molecular mechanisms of angiogenesis in GISTs–preclinical data

The regulation of angiogenesis is necessary for cancer cells initially to cope with their increased metabolic needs and in the process to promote their metastatic potential. Its significance was firstly recognized by Folkman[12], which stated that the magnified rate of neovascularization compared with wound healing and inflammation as a result of an interplay between tumor cells and endothelial cells was a prerequisite in order to achieve tumor growth[12]. Presently, it is widely known that the
angiogenic process is being coordinated by the balance of several angiogenesis inducers and inhibitors in tumor’s microenvironment. The dominance of the pro-angiogenic factors, a phenomenon called “angiogenic switch”[13], triggers the angiogenesis and could result either as result of the consequent hypoxia from the increased tumor proliferation or by the immune cell infiltration[14]. The primary induction phase with the undeveloped vessels paves the way for the remodeling phase when the blood vessel generation is sustained[15]. Several models of angiogenesis have been described explaining partially the poor outcomes of the selective angiogenic blockage as certain tumors can utilize alternative modes of angiogenesis[14]. Their analytical presentation has been done elsewhere[14,16,17] and goes beyond the scope of this review but a brief presentation in Table 1 would be helpful.

Xenograft studies in mice constitute an invaluable source of evidence about the angiogenic mechanisms in GISTs. Our fundamental conceptualization about the orchestration of the angiogenic process descended from Giner et al[18]. They utilized an intensely CD117, DOG1 and CD34-positive GIST with continual Ki-67 expression in about 15% of the tumor’s mass. The neovascularization experiments demonstrated the propagation of the induction phase during the first 96 h after implantation which proceeded by the remodeling phase. The induction phase was guided by the VEGF, VEGFC, PDGFA, PDGFB gene expression in conformity with their receptors. In more detail, the IHC data indicate that the VEGF ligand and the VEGFR2, VEGFR3 were positive at day 4 after the xenografting. As regards the chemokine expression, CXCL9, CXCL10, GRO and their receptors CXCR3, CXCR2 were stained in tumor cells and stroma soon after the implantation with a slight staining predominance of the chemokine receptors. These effects are possibly orchestrated by hypoxia-inducible factor (HIF)Iα and the CXCL12/CXCR4 axis, which are constantly expressed[18].

The angiogenic process in GIST has been further delineated and several regulatory molecules have been identified. CCL2 represents a chemokine expressed by the tumor cells to attract CCR2-expressing endothelial progenitor cells from the circulation as documented in HER-2/neu-driven breast cancer[19]. On the other hand, the VEGF-induced nuclear factor kappa B (NF-kB) upregulation is frequently utilized to attract inflammatory cell into tumor to stimulate the angiogenesis[20]. The bromodomain and extraterminal domain family mediates immunity regulating several signaling pathways[21]. In GISTs, the BRD4 upregulation enhanced the migratory and invasion processes regulating angiogenesis through the NF-kB/CCL2 signaling pathway. The BRD4-expressing cells attract tumor-associated macrophages via the expression of CCL2 potentiating the tumor’s microvessel density and secrete various pro-angiogenic molecules such as VEGFA, LOX and MMP9[22,23]. Towards the same direction, mutations of the protein phosphatase 2, regulatory subunit A, alpha (PPP2R1A) affect the carcinogenesis process[24,25]. In GISTs, mutations in PPP2R1A gene are found in nearly 20% of the cases and correlate with a more aggressive tumor phenotype. They result in increased growth rate via enhancing phosphorylation of c-kit, Akt1/2, ERK1/2 and WNK1. The latter seems to mediate the regulation of the angiogenic process[26,27]. A further analysis of the specific mechanisms would be of great value and it should be applied.

Furthermore, while the contribution of epigenetic mechanisms in the GIST progression is well established, its impact in the angiogenic mechanisms could be further delineated. Several gaps in our understanding that remain unaddressed by the subdivisions according to the driver gene mutation status could be further elucidated by the tumor’s epigenetic landscape. The alterations in the tumor’s methylation profile are associated with a more aggressive phenotype[28] and the methylation status of the CD133 could reshape the management of the disease and it would be presented below in more depth[29]. The KDM4 family members (KDM4A-D) reshaping the structure of chromatin are implicated in the pathogenesis of a wide variety of cancers[30]. In GIST, the upregulation of KDM4D potentiates the angiogenesis in vivo, as indicated by the overexpression of CD31 in IHC. These effects are mediated by the HIF1β/VEGFA pathway in the presence of demethylation in the promoters of the H3K9me3 and H3K36me3 genes[31].

Finally, it is worth mentioning that several multi-TKIs exert their anti-tumor efficacy at least partially by the inhibition of angiogenesis. Cabozantinib exerts its activity inhibiting the receptor tyrosine kinases MET, VEGFR2, Flt-3, c-Kit and RET[32,33] while sorafenib inhibits the signaling of VEGFR-1, VEGFR-2, VEGFR-3, PDGFR-β, Flt-3, c-Kit and the Raf serine/threonine kinases[34]. Both diminish the tumor’s microvascular density as evidenced by CD31 IHC[35,36].

The association between imaging data and angiogenesis in GISTS

There have been several classification systems to stratify the malignant potential of GISTs such as: The National Institutes of Healthv consensus criteria (Fletcher’s criteria), the Armed Forces Institute of Pathology criteria (Miettinen’s criteria) or the International Union against Cancer TNM classification. Their main drawback constitute the inability to validate the tumor’s aggressiveness without surgical resection and detailed pathologic examination of the entire tumor to estimate the mitotic count[37,38]. Although taking into consideration the current therapeutic trends, the management of the advanced, unresectable disease is unequivocal, there are margins for improvement in the management of primary localized disease, especially in small-sized tumors. It could not be emphasized enough that even small GISTS could develop malignant behavior. Thereat, it could provide us a wealth of valuable predictive and prognostic information an attempt to incorporate imaging data about the vascularization of the tumor such as the vessels’ irregularity or the blood perfusion[39].
Table 1 The basic mechanisms of angiogenesis

| Angiogenic mechanism                      | Function                                                                 | Implanted signaling/ pathways                      |
|------------------------------------------|--------------------------------------------------------------------------|---------------------------------------------------|
| Sprouting angiogenesis                   | Vessel formation from a parental one as a sprout outgrowth               | VEGF, Dll4/notch pathways and neuropilins         |
| Intussusceptive Angiogenesis             | Splitting of a parental vessel into two newly formed                     | VEGF, PDGF pathways and erythropoietin             |
| Vasculogenesis/Endothelial progenitor cells | Vessel formation from endothelial progenitor cells differentiating into mature endothelial cells | VEGF pathway, chemokines                          |
| Vasculogenic mimicry                     | Vessel-like formations without endothelial cells                          | HGFR                                              |
| Trans-differentiation of CSCs            | CSC give rise to endothelial cells                                        | Tie-2, TGF-, CXCL12/CXCR4                         |

Table 1: The above indicate that CE-US comprises a powerful tool towards the more personalized approach in the management of GIST. The utilization of EUS has emerged during the last decades. Its ability to evade the intervention of the abdominal fat and gastrointestinal gas in conjunction with the capability of FNA biopsy to address the clinical manifestations of GIST. Reviewing past literature, several studies have documented that aim to associate certain imaging features with pathologic parameters. Iannicelli et al. [40] presented that GISTs with irregular margins tended to have superior mitotic rate than tumors with regular margins. Furthermore, a heterogenous pattern of contrast enhancement (CE), the angiogenesis and necrosis correlated with an increased tumor size and a more aggressive clinical behavior. It worth mentioning that the intensity of CE although it represents a novel mark of biologic activity, was not correlated with neither the number of mitoses nor the tumor’s risk stratification [40]. The above comprise an indirect link between tumor’s margins and mitotic rate, which is essential in order to stratify before surgery the clinical behavior of the tumor and highlight the importance of angiogenesis in disease progression. The latter could also be deduced by dynamic positron emission tomography analysis. Strauss et al. [43] reported an association between the rate in which the F-18-fluorodeoxyglucose diffused into the tumor with the expression of VEGF-A [43]. The main limitation of CT comprises its low sensitivity as regards the imaging of vascularity in small sized tumors [39]. This divergence could be addressed by the endoscopic ultrasound (EUS) technology.

Angiogenesis mediators as biomarkers in GIST—clinical data

The development of biomarkers comprises an essential step towards the individualization of medical practice. Liquid biopsy provides a cutting-edge, non-invasive technology to access predictive information to guide the therapeutic management in a wide variety of diseases [47-51]. Its application in GIST treatment has been started to emerge [52,53]. Reviewing subsequent and more recent literature, an extensive number of studies has been found associating molecules implicated in angiogenesis with pathologic features. Although there are several limitations in the above mentioned research, the
Table 2 A brief presentation of several angiogenetic molecules in disease progression

| Ref.                        | Sample size                                      | Molecule/methods                        | Outcomes                                                                 |
|-----------------------------|--------------------------------------------------|------------------------------------------|--------------------------------------------------------------------------|
| Zhao et al[59]              | 124 patients-62, 50% in stomach, 22.6% in small intestine | HIF-1α/IHC, VEGF/IHC, MVD/IHC            | Association with disease-free survival \(P = 0.03\), Association with disease-free survival \(P = 0.002\), Association with disease-free survival \(P < 0.001\) |
| Kang et al[60]              | 213 patients-63% in stomach, 25.3% in small intestine | 634G/C                                   | Superior OS than 634 G/G \(P = 0.054\), Superior RFS than 634 G/G \(P = 0.082\) |
| Mu et al[22]                | 20 patients                                       | BRD4/mRNA, IHC                           | Increased BRD4 expression compared with normal tissue                    |
| Toda-Ishii et al[61]        | 94 patients-mean follow-up period 65 mo           | PPP2R1A mutations/PCR                    | Lower OS \(P < 0.05\), Lower DFS \(P < 0.05\)                          |
| Liu et al[62]               | 52 patients-27 malignant cases-11 borderline-14 benign | MMP-9, COX-2, VEGF/IHC                   | Enhance metastasis \(P = 0.014, P = 0.010, P = 0.032\) respectively \(P = 0.002\) |
| Takahashi et al[63]         | 55 patients: 21 cases < 30 mm-9 cases with liver metastasis | VEGF/IHC, VEGF/IHC, MVD/IHC             | Association with liver metastasis \(P < 0.01\), Poor 10-yr OS \(P < 0.05\), Association with liver metastasis \(P < 0.05\) |
| Verboom et al[64]           | 227 patients-36 SNPs-18 genes, median PFS 39 mo-median OS 86.5 mo | rs1570360 polymorphism in VEGFA gene, rs1870377 polymorphism in VEGFR2 gene | Association with poorer PFS \(P = 0.015\), Association with lower PFS \(P = 0.037\) |
| Chen et al[65]              | 62 patients: 31 high risk-31 low risk             | HIF-1α/IHC, VEGF/IHC                    | Association with high risk disease \(P < 0.0001\), Association with GIST recurrence or metastasis \(P = 0.009\) |
| Basilio-de-Oliveira and Pannain[66] | 54 patients                                         | VEGF/IHC, CD105/IHC                       | Association with survival \(P < 0.001\), Association with prognosis \(P < 0.001\) |
| Imamura et al[67]           | 95 patients: 64 cases in stomach-31 in small intestine | MVD/IHC                                   | Association with tumor grade \(P = 0.036\), Association with VEGF expression \(P < 0.0001\), Association with DFS after surgery \(P = 0.0028\) |
| Wang et al[68]              | 68 patients: 20 low risk cases-48 high risk cases | Soluble VEGF, VEGF/IHC, MVD/IHC          | Association with lower DSS \(P < 0.05\)                                 |

OS: Overall survival; DSS: Disease-specific survival; DFS: Disease-free survival; PFS: Progression-free survival; VEGF: Vascular endothelial growth factor; IHC: Immunohistochemistry; MVD: Microvascular density; HIF: Hypoxia-inducible factor.

The importance of angiogenesis in GIST's malignant progression is delineated. In Table 2 are summarized the most significant data.
CONCLUSION

As highlighted above, angiogenesis mediates an extensive proportion of GIST's malignant dynamics. Several signaling pathways are implicated in the regulation of angiogenesis such as: The VEGF, the fibroblast growth factor-2 (FGF2), the PDGF, the angiopoietins, the Eph/ephrin signaling, the Apelin/APLN pathway, the HIFs and several chemokines[14]. The VEGF signaling comprises the most well-studied pathway in GIST angiogenesis.

The FGF2/R2 signaling has been extensively studied in GIST as a drug resistance mechanism. Sergei et al.[54] and Boichuk et al.[55] demonstrated that the blockage of FGFR2 signaling could enhance the responsiveness to DNA-Topoisomerase II inhibitors[54] while the downregulation of FGF2 signaling might stimulate the response to imatinib[55]. Its contribution in GIST progression has been reviewed [56] but data about potential effects in GIST vascularization process are missing. Towards the same direction, the Eph/ephrin system has been investigated in carcinogenesis[57,58]. It would be of paramount importance an attempt to outline its contribution in GIST angiogenesis.

FOOTNOTES

Author contributions: Papadakos SP and Tsagkaris C contributed equally; Papadakos SP and Tsagkaris C contributed to the onceptualization and study design; Papadakos SP wrote the first draft; Moysidis DV, Papazoglou AS, Papadakis M and Zografos CG wrote the second draft; Tsagkaris C, Papadakis M and Theocharis S contributed to the critical revision; Papadakis M and Theocharis S contributed to the supervision

Conflict-of-interest statement: All the authors report no relevant conflicts of interest for this article.

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S-Editor: Fan JR
L-Editor: A
P-Editor: Fan JR

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