MET overexpression and gene amplification in NSCLC: a clinical perspective

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Abstract: The transmembrane tyrosine kinase mesenchymal-epidermal transition (MET) receptor and its ligand, hepatocyte growth factor, also known as scatter factor, have recently been identified as novel promising targets in several human malignancies, including non-small cell lung cancer (NSCLC). Amplification, mutation, or overexpression of the MET gene can result in aberrant activation of the MET axis, leading to migration, invasion, proliferation, metastasis, and neoangiogenesis of cancer cells, suggesting that interfering with the MET/hepatocyte growth factor pathway could represent a potential antitumor strategy. While the role of MET mutations in NSCLC is not as yet fully understood, retrospective studies have shown that an increased MET gene copy number is a negative prognostic factor. In NSCLC, amplification of the MET gene is a relatively rare event, occurring in approximately 4% of patients not previously exposed to systemic therapies and in up to 20% of patients with acquired resistance to epidermal growth factor receptor tyrosine kinase inhibitors. In preclinical models, the presence of MET amplification is a predictor of high sensitivity to anti-MET compounds, and several agents have entered in clinical trials for patients having advanced disease, with promising results. The aim of the present review is to summarize available data on the role of MET in NSCLC and to describe therapeutic strategies under investigation.

Keywords: mesenchymal-epidermal transition, hepatocyte growth factor, epidermal growth factor receptor, non-small cell lung cancer

Introduction

For many years, non-small cell lung cancer (NSCLC) has been considered as a unique monochromatic disease with an unfavorable prognosis and limited therapeutic options.1 This old perspective is now changing dramatically with identification of the molecular events driving tumor growth and development, leading to so-called targeted therapies.2 Up until now, gene mutations, gene amplification, and gene rearrangements have been among the most widely investigated aberrations in human cancer.

In NSCLC, identification of epidermal growth factor receptor gene (EGFR) mutations and EML4 -anaplastic lymphoma kinase (ALK) translocation led to definition of different clinical entities with different therapeutic opportunities.3–7 Clinical trials confirmed that targeted therapies are the best treatment option we can offer today to our patients and only when the target is present, with no benefit or even a detrimental effect when a targeted agent is given in unselected populations.8–19 Seven large randomized Phase III trials conducted in more than 1400 patients harboring classical EGFR mutations, such as a deletion in exon 19 or an L858R substitution in exon 21, have demonstrated the superiority of gefitinib, erlotinib, and afatinib in terms of response...
rate and progression-free survival when compared with conventional platinum-based chemotherapy. Although no formal overall survival advantage has emerged from the aforementioned trials, mainly because of a drug crossover effect, median survival reached 2–3 years, indicating that EGFR tyrosine kinase inhibitors are changing the natural history of EGFR-mutated NSCLC. More recently, two studies, A8081001 and PROFILE 1007, established crizotinib as the best treatment for the small population of patients with ALK-translocated NSCLC.

Unfortunately, often medicine is like Janus, the God with two faces, and the dark side in this context is represented by emergence of acquired resistance. Indeed, despite dramatic initial tumor regression, virtually all patients exposed to such targeted agents develop resistance after a median time of 10 months and inevitably progress and die from their disease.

Amplification of the MET gene has been recognized as one of the most prominent mechanisms responsible for secondary resistance to EGFR tyrosine kinase inhibitors, and several sets of preclinical and clinical data indicate that coinhibition of MET and EGFR is a potentially effective strategy to overcome acquired resistance to these agents. Further, because of its central role in the proliferation and metastasis of cancer, MET has recently emerged as a potential tumor driver and also a promising target in NSCLC. Here, we discuss the role of the mesenchymal-epidermal transition (MET) receptor, its abnormalities in cancer, and the clinical impact of anti-MET strategies in NSCLC.

**MET and NSCLC**

The MET gene encodes for the hepatocyte growth factor (HGF, also known as scatter factor) receptor, a transmembrane tyrosine kinase heterodimer protein involved in a complex signaling apparatus. HGF is produced particularly by stromal tissues and is also expressed in a broad spectrum of mesenchymal cells. Binding of HGF to the extracellular domain of the receptor determines autophosphorylation of the catalytic site and consequently activation of the downstream signaling cascade in a domino-effect fashion (Figure 1).

In physiological conditions, such as during embryogenesis or organogenesis, activation of the MET/HGF pathway regulates a wide network of signaling that leads to "invasive growth", a phenomenon in which the cell gains the ability to move from its original niche toward the surrounding microenvironment, growing and improving proliferation and survival. This process becomes quiescent in adulthood, but different stressing conditions, such as angiogenesis or hypoxia, can lead to its reactivation. Notably, the HGF/MET axis also plays an important role in regulating tissue homeostasis and the inflammatory tissue response, as elucidated in preclinical models of degenerative diseases, including nephropathies and multiple sclerosis.

In cancer, aberrant activation of the MET/HGF pathway, either through ligand-dependent or ligand-independent mechanisms, is a frequent event and has been described in several human malignancies, including NSCLC, glioma, and gastroesophageal, ovarian, breast, kidney, and liver cancer, strongly supporting the hypothesis that interfering with the MET/HGF pathway could represent a potential antitumor strategy.

Several mechanisms are responsible for MET dysregulation, including protein overexpression, gene amplification, or gene mutation. Overexpression of MET is frequently observed in human cancer, including NSCLC, where this event is observed in 25%–75% of cases. In the absence of gene amplification, overexpression of MET could be related to transcriptional upregulation, and in some tumors the extent of expression has correlated with disease extension and outcome. The presence of a high number of receptors on the cell surface causes receptor oligomerization, thus determining an increased sensibility to suboptimal ligand concentrations.

**Figure 1** Hepatic growth factor/mesenchymal-epidermal transition axis.

Abbreviations: HGF, hepatic growth factor; mAbs, monoclonal antibodies; TKI, tyrosine kinase inhibitor; P13K, Phosphatidylinositide 3-kinase; MET, mesenchymal-epidermal transition.
of 534 surgically resected NSCLCs were analyzed for MET gene copy number by quantitative real-time polymerase chain reaction. The study showed that an increased MET gene copy number was significantly associated with poor survival. In 2009, we analyzed a cohort of 447 surgically resected NSCLC for EGFR and MET gene copy number using fluorescence in situ hybridization. In this study, we observed that MET amplification is a relatively rare phenomenon in NSCLC, occurring in approximately 4% of cases. Interestingly, patients with a mean of five or more MET gene copies had a significantly worse survival than individuals with a low increase in MET gene copy number (mean below five), demonstrating that MET is a negative prognostic factor in NSCLC. In the last few years, growing interest has been focused on the impact of increased MET gene copy number in the setting of EGFR-mutant patients. Indeed, MET amplification is responsible for acquired resistance to EGFR tyrosine kinase inhibitors in up to 20% of EGFR-mutant patients, while in EGFR tyrosine kinase inhibitor-naïve patients, MET amplification occurs in less than 5% of cases. Coamplification of both MET and EGFR is a very rare event, occurring in less than 1% of cases. In a previous experience, we observed that MET amplification levels detected in EGFR tyrosine kinase inhibitor-naïve patients were generally lower than those observed in cell lines with acquired resistance to EGFR tyrosine kinase inhibitors. Based on these findings, we supposed that high levels of MET amplification, known to be associated with gefitinib resistance in vitro, rarely occurs in untreated NSCLC, irrespective of EGFR status, and may develop only under therapeutic pressure, leading to the conclusion that, in EGFR tyrosine kinase inhibitor-naïve patients, the level of genomic gain for MET is not increased enough to impact the response to tyrosine kinase inhibitors. These findings suggest that anti-MET strategies could be more effective in patients resistant to EGFR tyrosine kinase inhibitors than in EGFR TKI naïve.

Finally, another mechanism responsible for MET dysregulation is gene mutation, an event occurring in approximately 5%–10% of NSCLCs. Several different MET mutations have been described in sporadic human cancer, including papillary renal cell carcinoma, and gastric and lung cancers. Distribution of MET mutations varies widely across ethnic and racial lines, with the highest frequency occurring in East Asians, while according to the type of mutation, they occur mainly in the non-tyrosine kinase domain followed by the juxtamembrane and sema domain. Intriguingly, the presence of mutations has been preferentially found in metastatic lesions compared with primary lesions. All these and other mechanisms of MET/HGF axis activation has been described in detail elsewhere.

**Targeting MET**

There are at least four possible strategies that are useful for blockade of the HGF/MET pathway, ie, agents interfering with HGF binding to MET, anti-MET monoclonal antibodies, small molecule MET kinase inhibitors, and small molecule downstream pathway inhibitors of STAT3. More interestingly, data from preclinical studies suggest that the modality of HGF/MET activation, such as autocrine/paracrine stimulation, gene amplification, or mutation, is crucial to be able to predict the class of agents that can effectively interrupt the signaling pathway. A list of anti-MET agents currently under investigation in NSCLC clinical trials is shown in Table 1.

<table>
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<tr>
<th>Agent</th>
<th>Target</th>
<th>Type</th>
<th>Development phase</th>
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<td><strong>Ligand antagonists</strong></td>
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<td>Ficlatuzumab (AV-299)</td>
<td>HGF</td>
<td>Monoclonal antibody</td>
<td>I and II</td>
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<td>Rilotumunab (AMG-102)</td>
<td>HGF</td>
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<td>TAK-701</td>
<td>HGF</td>
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<td><strong>Receptor inhibitors</strong></td>
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<td><strong>Receptor TKIs</strong></td>
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<td>Tivantinib (ARQ-197)</td>
<td>MET</td>
<td>Non-ATP competitive TKI</td>
<td>II and III</td>
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<td>Cabozantinib (XL-184)</td>
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<td>ATP competitive TKI</td>
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<td>Foretinib (XL-880)</td>
<td>MET, RON, VEGFR1-3, PDGFR, KIT, FLT3, TIE2</td>
<td>ATP competitive TKI</td>
<td>II</td>
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<tr>
<td>Crizotinib (PF-02341066)</td>
<td>MET, ALK</td>
<td>ATP competitive TKI</td>
<td>II and III</td>
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<tr>
<td>MGCD-265</td>
<td>MET, RON, VEGFR1-2, PDGFR, KIT, FLT3, TIE2</td>
<td>ATP competitive TKI</td>
<td>II</td>
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**Abbreviations:** ALK, anaplastic lymphoma kinase; ATP, adenosine triphosphate; FLT3, fms-related tyrosine kinase 3; HGF, hepatocyte growth factor; MET, mesenchymal-epidermal transition; PDGFR, platelet-derived growth factor receptor; RET, rearranged during transfection; TKI, tyrosine kinase inhibitor; VEGFR, vascular endothelial growth factor receptor.
HGF antagonists

HGF antagonists prevent interaction between the ligand and receptor. HGF has two MET binding sites, one with high affinity and one with low affinity, accessible only to HGF and essential for MET dimerization and activation.62 NK2 is a truncated protein product of a natural alternative HGF mRNA transcript that competitively antagonizes growth stimulated by full length HGF.64 However, the potential antioncogenic efficacy of NK2 was found to be compromised by its intrinsic mitogenic activity, which enhanced HGF-driven metastasis in mouse models.65

NK4 is a longer truncated isoform of full length HGF proven to be a complete competitive antagonist of HGF-cMET signaling in preclinical models, and has been tested by administration of the purified protein or as gene therapy.66–69 Unexpectedly, NK4 has been reported to inhibit angiogenesis induced by secreted factors, such as vascular endothelial growth factor receptor (VEGF) and basic fibroblast growth factor, and this angioinhibitory activity is independent of its action as an HGF antagonist.67 Importantly, NK4 protein and NK4 gene therapy have been shown to inhibit tumor invasion, metastasis, and angiogenesis, as demonstrated in in vivo models of colorectal and pancreatic cancers.67 Nevertheless, despite an exciting scenario for clinical development of such agents, no final reports of further drug development, activity, or safety are available as yet.69

Onartuzumab

Blockade of the HGF/MET cascade can be achieved successfully using antibodies directed against the extracellular domain of MET. Activity of monoclonal antibodies against MET was first demonstrated in preclinical models of glioblastoma, and pancreatic, gastric, and breast cancers, where tumor growth is sustained by autocrine or paracrine stimulation of the HGF/MET axis.70,72

Onartuzumab (MetMab®, Genentech, Roche, Basel, Switzerland) is a fully humanized monoclonal antibody. Unlike classical bivalent monoclonal antibodies, its one-armed structure permits binding to the extracellular domain, thus avoiding receptor dimerization. Initial data on the safety and activity of onartuzumab administered intravenously every two or three weeks alone or in combination with bevacizumab were reported in two Phase I trials.73,74 In 2011, Spigel et al presented the results of a randomized Phase II study comparing onartuzumab + erlotinib versus erlotinib alone in 128 pretreated patients with NSCLC.75 The two coprimary endpoints of the study were progression-free survival in the entire population and progression-free survival in patients with high MET expression, defined as ≥50% of tumor cells staining moderately or strongly for MET by immunohistochemistry. Although the study did not meet the primary endpoint in the whole population, the risk of progression was significantly lower in patients with high MET expression (progression-free survival 3.0 versus 1.5 months; hazards ratio 0.47; P = 0.002). Intriguingly, a potentially detrimental effect in the experimental arm was observed for patients with low MET expression. Overall, these data suggested that onartuzumab in combination with erlotinib could be more effective than erlotinib alone in pretreated patients with NSCLC and high MET expression. A confirmatory Phase III study is currently ongoing.

Antibodies against HGF

Several monoclonal antibodies against HGF have been evaluated for their ability to prevent interaction of HGF with MET and consequently inhibit MET activation and the downstream cascade.76–78 In HGF/MET loop-dependent xenograft models, different anti-HGF antibodies demonstrated activity when used alone or in combination with chemotherapy.78

Ficlatuzumab (AV 299, Aveo Pharmaceuticals Inc, Cambridge, MA, USA) is a potent high-affinity HGF blocker. Since its initial development, it has been evaluated in combination with erlotinib or gefitinib in patients with pretreated advanced NSCLC.79,80 Results emerging from these trials indicated a favorable toxicity profile and interesting activity in five of the 12 treated patients.79 In a small group of Asian patients with unresectable and pretreated NSCLC, a combination of gefitinib and ficlatuzumab showed a promising response rate of 33% with manageable toxicity.80 On this basis, Asian researchers designed a randomized Phase II trial comparing standard gefitinib versus the combination of gefitinib and ficlatuzumab in 188 never-smokers or light-former smokers with lung adenocarcinoma. The primary end point was efficacy in terms of response rate. The study failed to demonstrate a significant increase in overall response rate in favor of the experimental arm. Nevertheless, exploratory analyses revealed a significant improvement in survival for patients with high stromal HGF levels treated with the combination, while a non-significant trend favoring survival was noted for patients who were immunohistochemically MET-positive and had wild-type EGFR tumors.81

Rilotumumab (AMG 102, Amgen, Thousand Oaks, CA, USA) is a fully humanized monoclonal antibody that neutralizes HGF/SF.82 Early Phase I studies explored the safety of this new drug alone or in combination with other targeted agents, such as motesanib or bevacizumab. Overall, these
studies highlighted a moderate incidence of adverse events, mainly fatigue, nausea/vomiting, and hypertension.53,84 However, rilotumumab failed to demonstrate efficacy in a Phase II trial conducted in unselected patients with recurrent glioblastoma multiforme.85

Another anti-HGF antibody recently introduced into early-phase development is TAK 701.86

In EGFR-mutant/HGF-expressing human clones, the combination of TAK 701 and gefitinib produced a marked inhibition of MET, EGFR, and Akt.87 Additional studies are needed to define the role of this compound.

**MET tyrosine kinase inhibitors**
The catalytic activity of MET can be blocked by small molecule inhibitors that generally compete for the adenine triphosphate (ATP) binding site in the tyrosine kinase domain of MET, thus preventing the downstream signaling cascade. From a practical point of view, MET tyrosine kinase inhibitors belong to two main categories, depending on their specificity for MET or for other targets, such as VEGFR, platelet-derived growth factor receptor, fms-like tyrosine kinase 3 (FLT3), RON, and AXL. Use of a tyrosine kinase inhibitor seems to be particularly effective in tumors where MET activation is ligand-independent (ie, gene amplification or mutation).55,59,88–91

**Selective inhibitors**
Tivantinib (ARQ 197, ArQule®, Daiichii-Sankyo, Bethlehem, PA, USA) is an oral small molecule first defined as a proapoptotic agent and subsequently found to have specificity as an anti-MET compound.92 Indeed, tivantinib acts by binding to a non-phosphorylated form of MET, locking it in an inactive state.93 Preclinical in vitro and in vivo experience as well as Phase I dose-escalation studies suggested its potential activity in different types of cancer.92–95 In the ARQ-197-101 and ARQ-197-103 studies,94,95 respectively, 79 and 51 heavily pretreated patients with a broad spectrum of solid malignancies received increasing doses of tivantinib, ranging from 10 mg to 400 mg twice daily. According to the dose-limiting toxicities (mainly febrile neutropenia and grade 3 mucositis) observed in the ARQ-197-103 trial, 360 mg twice daily emerged in both trials as the recommended dose to use in Phase II studies. Interest in combining dual EGFR-MET inhibition in the clinical setting led to exploration of the feasibility of a combination of erlotinib and tivantinib. In the ARQ-197-111 trial, 32 patients with advanced solid tumors (of which 25% were NSCLC) were exposed to erlotinib at the standard dose of 150 mg daily and oral tivantinib in an escalating fashion.96 Although the maximum tolerated dose was not reached, the safe dose of tivantinib for use in this combination was identified to be 360 mg twice daily. More interestingly, six of eight patients with NSCLC achieved a stable disease. In 2011, Sequist et al published the final results of a randomized Phase II trial in which 167 pretreated (with at least one chemotherapy regimen but not with erlotinib) patients with NSCLC were randomly assigned to erlotinib monotherapy or to a combination of erlotinib and tivantinib, with the aim of demonstrating an improvement in progression-free survival in favor of the experimental arm.97 Subjects enrolled in the combination arm did not have a significantly higher probability of response (10% versus 7%), with no evidence of increased adverse events. The study did not reach its primary endpoint of progression-free survival in the entire population (3.8 months versus 2.3 months for the experimental arm and standard arm, respectively), but a trend toward survival was observed in non-squamous histology (70% of the overall cohort) and in KRAS-mutant patients (14% of the overall cohort), while the presence of EGFR mutations seemed not to affect the outcome. Unfortunately, the Phase III MARQUEE study conducted in a larger cohort of patients with advanced chemotherapy-refractory non-squamous NSCLC failed to replicate the previous findings. On October 2, 2012, a press release from the company announced early interruption of this trial following a planned interim analysis in the intent-to-treat population that showed no survival gain for patients receiving the two drugs. It is important to note that the patients in this study were not selected based on biological characteristics, providing a potential explanation for the failure of this trial.

Several further selective MET inhibitors are under evaluation in solid tumors, including PF04217903, AMG 337, and INCB028060. Early data suggest that these agents are potentially effective and Phase I studies are ongoing.99–104

**Non-selective inhibitors**
Crizotinib (PF 02341066, Xalkori®, Pfizer, Mission, KS, USA) is a multitarget receptor tyrosine kinase inhibitor, and was initially synthesized as a MET inhibitor.105,106 In the Phase I trial (A8081001), an enriched cohort of 25 patients carrying a wide range of MET alterations received crizotinib, but impressive tumor shrinkage was only observed in MET-amplified tumors, such as NSCLC, gastroesophageal carcinoma, and glioblastoma.88–91 However, the occurrence of similarly dramatic responses in NSCLC cases harboring an ALK rearrangement shifted the enthusiasm of researchers towards clinical development of the drug in this molecularly defined setting.16–18
Other non-selective tyrosine kinase inhibitors targeting MET, RET, VEGF, KIT, FLT3, and RON, such as cabozantinib (XL184, Exelixis, San Francisco, CA, USA), foretinib (XL880, Exelixis), and golvatinib (E7050, Eisai, Tokyo, Japan) have been extensively evaluated, and several Phase I–III studies of these new agents are currently ongoing in patients with different type of malignancies such as gastric and medullary thyroid cancer, glioblastoma, and renal cell carcinoma.

Cabozantinib is an oral multitarget inhibitor of MET, VEGFR, FLT3, and KIT. Like tivantinib, cabozantinib has been evaluated in combination with erlotinib in patients with NSCLC and acquired resistance to erlotinib. In a Phase Ib/II trial, 54 patients with NSCLC received a combination of these two drugs in a 3 + 3 design using combination doses across five cohorts in two parallel arms. No unexpected side effects were observed, and the most frequent grade 3/4 adverse events were diarrhea, fatigue, dyspnea, and hypoxia. Among the 36 patients assessable for response, six had a ≥30% reduction in tumor size, including three who achieved a partial response, while prolonged stable disease for more than four months has been observed in some cases; notably, among the responders, one had a MET amplification and among patients with long-lasting tumor stabilization, one harbored the EGFR T790M mutation. The activity and safety of cabozantinib 100 mg daily was further evaluated in a large randomized Phase II discontinuation trial conducted in 483 patients with nine different tumor types, including NSCLC. Grade 3 fatigue, hand–foot skin reaction, and hypertension were the main class effects reported, while antitumor activity was observed across all tumor types. Interestingly, in the NSCLC cohort (n = 60), tumor regression was seen in 64% of evaluable patients, with six (13%) patients experiencing a partial response; notably, some of the responders had a known driver mutation at baseline (three EGFR mutations, three KRAS mutations), while non-responders did not. Nevertheless, the small sample size does not allow definitive conclusions concerning the effect of EGFR or KRAS mutations on response.

Foretinib is an ATP-competitive dual inhibitor of MET and VEGFR. Two Phase I studies with different schedules of administration have been done in patients with advanced solid tumors. In both trials, hypertension, diarrhea, fatigue, vomiting, and proteinuria were the main toxicities observed. Based on the observation that combination of foretinib with an anti-HER agent (erlotinib or lapatinib) produced a remarkable decrease in MET, HER1, HER2, HER3, Akt phosphorylation in cell lines, a Phase I/II study of erlotinib with or without foretinib is now under way.

Golvatinib also inhibits MET and VEGFR, and in vitro models have demonstrated the ability of this agent to prevent emergence of resistance to EGFR tyrosine kinase sustained by HGF. A Phase I study in adults with advanced solid tumors established 400 mg daily as the recommended dose, while fatigue, diarrhea, nausea/vomiting, and increased transaminase levels were the typical toxicities.

Early clinical trials of MGC D265 and ANG707, two of the newest non-selective MET inhibitors, have just started recruitment, and it is planned to give these agents as monotherapy or in combination with erlotinib.

### Downstream signaling pathway

OPB-31121 is a small molecule that inhibits interleukin-6-induced phosphorylation of STAT3, leading to disruption of the JAK/STAT signaling pathway. In a Phase I dose-escalation study in patients with advanced solid tumors, including lung cancer, OPB-31121 produced disease stabilization in 47% of cases, with a favorable toxicity profile. The promising antitumor activity of this compound warrants further investigation.

### MET as a moderator of sensitivity to ionizing radiation

As previously discussed, activation of MET promotes epithelial–mesenchymal transition, hypoxia-related angiogenesis, and invasiveness of cancer, and a growing amount of data have demonstrated that these phenomena are closely related to resistance to ionizing radiation. Several preclinical investigations have suggested that MET was upregulated in irradiated cancer cells and how this event was influenced by HGF as well as by radiation dose and duration. In glioblastoma multiforme cell lines, radiation enhanced HGF levels, thus determining radioresistance. The same has been observed in neuroblastoma cells, where higher levels of HGF mRNA were founded in irradiated cells than in those not exposed to radiation; interestingly, the invasiveness of neuroblastoma cells was higher in the presence of elevated MET expression at baseline. In pancreatic cancer, increasing doses of radiation can stimulate MET expression and cancer invasiveness under HGF pressure. Recently, Li et al showed in a preclinical model of NSCLC that the combination of radiation therapy and MET inhibition with AMG-458 synergistically increased apoptosis in cells with constitutive phosphorylation of MET.

From a clinical point of view, in patients with oropharynx squamous carcinoma and treated with curative radiotherapy, MET overexpression negatively affected local failure.
free-survival, while HGF levels were inversely correlated with failure-free survival.\textsuperscript{125} Further, high MET levels, assessed by immunohistochemistry in nasopharyngeal carcinoma specimens, identified a subgroup of patients with worse outcome after local radiotherapy (five-year survival rate 48% versus 84% for high and low MET levels, respectively).\textsuperscript{126}

These data demonstrate that activation of MET is related to irradiation highlighting the potential role of MET inhibition in overcoming resistance to radiotherapy.

Discussion

During the last few years, advances in our knowledge of cancer biology have led to the development of strategies interfering with activation of the MET pathway. Nevertheless, at the present time, no anti-MET agent is available in clinical practice outside clinical trials, so the role of these agents remains promising but still undefined.

A critical issue concerns the biological selection of patients who are candidates for an anti-MET strategy and identification of the ideal predictive biomarker. It is important to highlight that none of the aforementioned trials included molecular selection of patients.\textsuperscript{75,80,81,88–91,97,115} Preplanned subgroup analyses suggest that overexpression of MET assessed by immunohistochemistry could be useful for predicting the efficacy of anti-MET monoclonal antibodies.\textsuperscript{75,127} Indeed, onartuzumab increased progression-free survival in patients with high MET expression, but had a detrimental effect in those with low or negative MET expression.\textsuperscript{75} Notably, in advanced gastric cancer, addition of rilotumumab to chemotherapy produced a higher response rate and longer survival than chemotherapy alone in patients with high MET expression.\textsuperscript{127} On the other hand, the results from trial A8081001 clearly demonstrated that crizotinib, a selective MET and ALK inhibitor, is active in NSCLC as well as in other malignancies only in presence of MET gene amplification.\textsuperscript{88–91} Overall, these data indicate that anti-MET therapy might be effective only in molecularly defined subgroups of patients.

Another hot topic is the optimal timing of introduction of an anti-MET agent in the treatment algorithm. Because of synergism with the EGFR pathway, the vast majority of trials have tested different anti-MET compounds in EGFR tyrosine kinase inhibitor-resistant or chemorefractory settings, and in this context, MET inhibition seemed to be potentially effective.\textsuperscript{75,80,81,88–91,97,98,115} Nevertheless, use of an anti-MET drug as front-line treatment should be considered in selected cases. In tumors for which MET dysregulation represents a real driver, probably the best way to maximize the therapeutic effect of anti-MET agents would be introduction of the drug early in the course of the disease, such as in the front-line setting. As a proof of concept, dramatic tumor regression in response to an anti-MET agent has been described in some MET-amplified NSCLC and gastric cancer cell lines, similar to that observed in EGFR-mutant clones exposed to erlotinib or gefitinib.\textsuperscript{128,129} Unfortunately, at the present time, no study has explored the role of anti-MET agents in the first-line setting for patients with NSCLC.

Finally, whether anti-MET compounds are more effective when administered as single agents or in combination with other drugs remains undefined. Earlier in this review, we reported that simultaneous inhibition of the MET and HER pathways using onartuzumab and or a MET tyrosine kinase inhibitor plus an anti-EGF agent appeared to be the most appropriate strategy for overcoming acquired resistance.\textsuperscript{70,21} Crosstalk between MET/HGF and other cellular signal transduction pathways, such as RON, FAS, HER2, and integrins, offers the opportunity to explore different therapeutic combinations.\textsuperscript{59,61} Recently, a novel link between MET and angiogenesis has been identified. Preclinical studies indicated that MET expression and activation are enhanced in the presence of hypoxia.\textsuperscript{130,131} As a consequence of antiangiogenic therapy, a decrease in tumor vascularization and hypoxic stress led to MET-dependent proliferation, and a combination of anti-VEGF and anti-MET therapies could prevent the occurrence of this event.\textsuperscript{130,131} Indeed, a Phase III trial comparing the anti-VEGF monoclonal antibody, bevacizumab, administered alone or in combination with onartuzumab is ongoing in glioblastoma, which is one of the most vascularized malignancies.\textsuperscript{132}

Conclusion

In summary, due to its central role in the proliferation and metastasis of cancer, MET has recently emerged as a promising target in NSCLC. The development of MET-targeted agents offers the opportunity to improve outcomes for patients, but careful biological selection remains crucial for better definition of which patients will benefit most from such treatment, and emerging data reinforce the conviction that target selection is mandatory. Results from ongoing trials are eagerly awaited because they might pave the path to new molecularly targeted treatments for NSCLC and new hope for our patients.

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References


93. Jarvis LM. One pill, many uses.


127. Iveson T, Donehower RC, Davidenko I, et al. Safety and efficacy of epirubicin, cisplatin, and capecitabine (ECX) plus rituximab (R) as first line treatment for unresectable locally advanced (LA) or metastatic (M) gastric (G) or esophagogastric junction (EGJ) adenocarcinoma. Eur J Cancer. 2011;47:S443.


