Risk of Serious Neutropenic Events in Cancer Patients Treated with Bevacizumab: A Meta-analysis

Fan Zhou1&*, Jiang-Hua Shao1,2&*, Lin-Quan Wu1,2, Xiang-Bao Yin1, Xin Yu1

Abstract

Bevacizumab has been approved for use in combination with chemotherapy to treat many types of cancer but associated neutropenic events, including febrile neutropenia, have been reported. To estimate the incidence and relative risk of neutropenic events in cancer patients treated with bevacizumab combination therapy, we searched PubMed, EMBASE, and Web of Science literature databases, as well as abstracts presented at the American Society of Clinical Oncology conferences, to identify relevant studies published from January 1966 to December 2011. Studies that compared bevacizumab plus chemotherapy or biological therapy with chemotherapy or biological therapy alone, and that had adequate safety data profiles, were selected for analysis. Statistical analyses were conducted to calculate the summary incidence rates, relative risks (RRs), and 95% confidence intervals (CIs) using fixed- or random-effects models. A total of 22 clinical trials involving 15,056 patients were included in the analysis. The summary incidences of high-grade neutropenia (HGN) and high-grade febrile neutropenia (HGFN) in patients receiving bevacizumab was 27.3% (95% CI: 26.4%-28.3%) and 3.91% (95% CI: 3.51%-4.37%), respectively. The risks of HGN (RR=1.10; 95% CI: 1.02-1.19; P=0.02) and HGFN (RR=1.31; 95% CI: 1.08–1.59; P=0.005) were significantly increased in bevacizumab-treated patients, compared to those who did not receive bevacizumab. The RR of bevacizumab-associated HGN, but not HGFN, varied significantly with tumor types (P=0.005). The increased risk of bevacizumab-associated neutropenic events was dose-dependent, as the RR was greater at a dose of 5 mg/kg/week than at 2.5 mg/kg/week. Our findings suggest that bevacizumab addition to cancer therapy significantly increases the risk of serious neutropenic events, and this risk may be dose-dependent.

Keywords: Bevacizumab - neutropenia - febrile neutropenia - cancer - meta-analysis

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Introduction

Vascular endothelial growth factor (VEGF) plays an important role in tumor growth, invasion, and metastasis by promoting tumor angiogenesis (Folkman, 2002; Kerbel, 2008). The human VEGF family consists of five members: VEGF-A, VEGF-B, VEGF-C, VEGF-D, and placental growth factor (PIGF), of which VEGF-A is considered the most important angiogenic factor in cancer (Sakurai et al., 2011). Bevacizumab (manufactured by Genentech Inc. as Avastin), a humanized monoclonal antibody that can bind to VEGF-A, has been demonstrated to effectively inhibit VEGF receptor binding, thereby preventing tumor angiogenesis (Rini et al., 2008). As a result, bevacizumab has been approved for use in combination with chemotherapy to treat many types of advanced cancers, including colorectal cancer, non–small cell lung cancer (NSCLC), breast cancer, renal cell carcinoma, and glioblastoma multiforme (Hurwitz et al., 2005; Rini et al., 2008; Baar et al., 2009; Miles et al., 2010).

Although bevacizumab is remarkably well-tolerated by patients, a distinct pattern of adverse effects that are thought to be related to angiogenesis inhibition has emerged (Geiger-Gritsch et al., 2010; Hapani et al., 2010). The most concerning of these effects are hypertension, proteinuria, wound healing, venous and arterial thromboembolic events, gastrointestinal perforations, and congestive heart failure (Hapani et al., 2009; Ranpura et al., 2010; Choueiri et al., 2011). Neutropenic events, including febrile neutropenia, are generally characterized as side effects of chemotherapy. They have a significant negative impact on mortality, morbidity, and healthcare costs, often leading to treatment delays and interruptions. Recently, Ranpura et al. (2011) found that neutropenic events are the second most common cause of fatal adverse events in cancer patients treated with bevacizumab.

The reported overall incidence of neutropenic events, including febrile neutropenia, associated with
bevacizumab therapy has varied substantially among clinical trials (Escudier et al., 2007; Reck et al., 2009; Tebbutt et al., 2010). Therefore, an accurate quantification of this risk remains to be performed. While a recent meta-analysis of published clinical trials indicated that bevacizumab is associated with increased risks of neutropenic events (Schutz et al., 2011), the risk factors of neutropenic events were not identified. To better understand the overall risk of neutropenic events imparted by bevacizumab therapy and to identify the underlying risk factors, we conducted a meta-analysis of the published randomized controlled trials (RCTs) that had investigated bevacizumab combination treatment of cancer patients and occurrence of neutropenic events.

Materials and Methods

Data sources

We conducted an independent review of citations listed on PubMed between January 1, 1966, and December 31, 2011. The key words used were “bevacizumab”, “Avastin” and “cancer”, and the search was limited to RCTs. The search strategy also used the following text terms to identify additional relevant information: “neutropenia”, “febrile neutropenia”, “angiogenesis”, and “VEGF”. In addition, abstracts and virtual meeting presentations published by the American Society of Clinical Oncology conferences (http://www.asco.org/ASCO) between January 2000 and December 31, 2011 were searched using the terms “bevacizumab” and “Avastin”. Independent searches of the EMBASE or Web of Science databases were performed to ensure that no clinical trials were missed. Each potentially relevant publication was reviewed by two investigators (FZ and JHS) and according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (www.prisma-statement.org). Any discrepancies were resolved by consensus. For each study, the following information was extracted: first author’s name, year of publication, trial phase, underlying malignancy, number of enrolled patients, treatment arms, number of neutropenic events in experimental and control arms, drug dose/schedule, median age, median follow-up, median treatment duration, and median progression-free survival.

The goal of this study was to determine whether bevacizumab contributes to the development of high-grade neutropenia (HGN) and/or high-grade febrile neutropenia (HGFN) in cancer patients. Therefore, the number of neutropenic and/or febrile neutropenic events reported in the safety profile section of each study was recorded. Only adverse events of grade 3 or higher (serious) according to the National Cancer Institute Common Toxicity Criteria (NCI-CTC, version 2 or 3; http://ctep.cancer.gov) were included in the analysis, as trials rarely report all-grade or low-grade neutropenia and febrile neutropenia.

Statistical analysis

All statistical analyses were performed by Review Manager (RevMan) version 5.0 (Copenhagen: Nordic Cochrane Centre, Cochrane Collaboration, 2008) or STATA 10SE statistical software (STATA, College Station, TX, USA). To calculate incidence, the number of patients with each adverse event and the number of patients receiving bevacizumab were used to derive the proportion of patients with adverse events and 95% confidence interval (CI) for each study. To calculate relative risk (RR), patients who received bevacizumab in combination with chemotherapy were compared with those in the same trial who received chemotherapy alone.

Both fixed-effects and random-effects models were considered in the meta-analyses. For each meta-analysis, the Cochran Q statistic and I² score were first calculated to assess heterogeneity among the proportions of the included trials. If the P-value was less than 0.1, the assumption of homogeneity was deemed invalid, and a random-effects model using the DerSimonian and Laird method was reported after exploring the causes of heterogeneity. Otherwise, results from the fixed-effects model were reported by using the inverse variance method. Statistical heterogeneity was evaluated using I² statistics, with values up to 25%, 25%–50%, and above 50% indicating low, moderate, and high levels of heterogeneity, respectively. A Chi-squared (χ²) test for heterogeneity was performed, for which P<0.1 was considered statistically significant. Subgroup analyses was performed to identify risk factors for neutropenia and febrile neutropenia with bevacizumab-based therapy. To explore a dose-effect relationship, the bevacizumab therapy group was further divided into those receiving low-dose (2.5, 5, or 7.5 mg/kg schedule, equivalent to a weekly dose of 2.5 mg/kg) and high-dose (10 or 15 mg/kg schedule, equivalent to a weekly dose of 5 mg/kg), as previously described (Ranpura et al., 2011). Subgroup analyses were also performed for the year that the study was performed, the tumor types, and the chemotherapy regimens used. Q statistics were used for comparison of subgroup results. Publication bias was
Our search yielded a total of 213 potentially relevant studies of bevacizumab, of which 159 were initially excluded for not meeting the inclusion criteria. An additional 32 trials were excluded for being duplicates, for having administering bevacizumab to both treatment and control groups, or not reporting adequate data for evaluation. Thus, 22 trials were selected for inclusion in the meta-analysis, including three phase 2 and 17 phase 3 studies evaluated using funnel plots and quantified by Begg’s test. A two-tailed P-value less than 0.05 was considered statistically significant.

**Results**

**Search results and study quality**

Our search yielded a total of 213 potentially relevant studies of bevacizumab, of which 159 were initially excluded for not meeting the inclusion criteria. After evaluating each remaining study, 22 RCTs were selected for the meta-analysis (Hurwitz et al., 2005; Sandler et al., 2006; Escudier et al., 2007; Herbst et al., 2007; Karrison et al., 2007; Miller et al., 2007; Allegra et al., 2009; Baar et al., 2009; Moehler et al., 2009; Reck et al., 2009; Robert et al., 2009; Van Cutsem et al., 2009; Brufsky et al., 2010; Burger et al., 2010; Kang et al., 2010; Herbst et al., 2007; Miller et al., 2007; Allegra et al., 2009; Baar et al., 2009; Moehler et al., 2009; Reck et al., 2009; Robert et al., 2009; Van Cutsem et al., 2009; Brufsky et al., 2010; Burger et al., 2010; Kang et al., 2010; Kindler et al., 2010; Miles et al., 2010; Okines et al., 2010; Rini et al., 2010; Tebbutt et al., 2010; Zalcman et al., 2010). The selection process is summarized in Figure 1.

Randomized treatment allocation sequences had been generated in all trials. Ten trials were double-blinded and

Table 1. Characteristics of Randomized Controlled Clinical Trials Included in the Meta-analysis

<table>
<thead>
<tr>
<th>Source (publication year)</th>
<th>Trial phase/underlying malignancy</th>
<th>Number of patients enrolled</th>
<th>Duration of follow-up, months</th>
<th>Concurrent treatment</th>
<th>Bevacizumab dose, mg/kg/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baar (2009)</td>
<td>2 breast cancer</td>
<td>49</td>
<td>NA</td>
<td>Docetaxel</td>
<td>5</td>
</tr>
<tr>
<td>Brufsky (2010)</td>
<td>3 breast cancer</td>
<td>684</td>
<td>10.2</td>
<td>Docetaxel</td>
<td>5</td>
</tr>
<tr>
<td>Miles (2010)</td>
<td>3 breast cancer</td>
<td>736</td>
<td>7.11</td>
<td>Paclitaxel</td>
<td>5</td>
</tr>
<tr>
<td>Miller (2007)</td>
<td>3 breast cancer</td>
<td>722</td>
<td>19.2</td>
<td>Capecitabine, taxane, or anthracycline</td>
<td>5</td>
</tr>
<tr>
<td>Robert (2009)</td>
<td>3 colorectal cancer</td>
<td>1237</td>
<td>27.10</td>
<td>Fluorouracil, oxaliplatin, and leucovorin</td>
<td>2.5</td>
</tr>
<tr>
<td>Allegra (2009)</td>
<td>3 colorectal cancer</td>
<td>210</td>
<td>20.7</td>
<td>Fluorouracil and leucovorin</td>
<td>2.5</td>
</tr>
<tr>
<td>Hurwitz (2005)</td>
<td>3 colorectal cancer</td>
<td>210</td>
<td>19.5</td>
<td>Capecitabine and irinotecan</td>
<td>2.5</td>
</tr>
<tr>
<td>Moehler (2009)</td>
<td>2 colorectal cancer</td>
<td>46</td>
<td>46</td>
<td>Capecitabine and cisplatin</td>
<td>2.5</td>
</tr>
<tr>
<td>Tebbutt (2010)</td>
<td>3 colorectal cancer</td>
<td>471</td>
<td>313</td>
<td>Capecitabine and cisplatin</td>
<td>2.5</td>
</tr>
<tr>
<td>Kang (2010)</td>
<td>3 gastric cancer</td>
<td>774</td>
<td>767</td>
<td>Capecitabine and cisplatin</td>
<td>2.5</td>
</tr>
<tr>
<td>Okines (2010)</td>
<td>2 breast cancer</td>
<td>104</td>
<td>104</td>
<td>Gastric cancer</td>
<td>5</td>
</tr>
<tr>
<td>Karrison (2007)</td>
<td>3 prostate cancer</td>
<td>108</td>
<td>108</td>
<td>Prostate cancer</td>
<td>5</td>
</tr>
<tr>
<td>Zalcman (2010)</td>
<td>2 breast cancer</td>
<td>111</td>
<td>94</td>
<td>Breast cancer</td>
<td>5</td>
</tr>
<tr>
<td>Sandler (2006)</td>
<td>3 NSCLC</td>
<td>878</td>
<td>867</td>
<td>NSCLC</td>
<td>5</td>
</tr>
<tr>
<td>Herbst (2007)</td>
<td>2 NSCLC</td>
<td>122</td>
<td>120</td>
<td>NSCLC</td>
<td>5</td>
</tr>
<tr>
<td>Reck (2009)</td>
<td>3 pancreatic cancer</td>
<td>1043</td>
<td>986</td>
<td>Pancreatic cancer</td>
<td>5</td>
</tr>
<tr>
<td>Burger (2010)</td>
<td>3 ovarian cancer</td>
<td>1873</td>
<td>1816</td>
<td>Ovarian cancer</td>
<td>5</td>
</tr>
<tr>
<td>Kindler (2010)</td>
<td>3 mesothelioma</td>
<td>602</td>
<td>540</td>
<td>Mesothelioma</td>
<td>5</td>
</tr>
<tr>
<td>Van Cutsem (2009)</td>
<td>3 prostate cancer</td>
<td>607</td>
<td>583</td>
<td>Prostate cancer</td>
<td>5</td>
</tr>
<tr>
<td>Kelly (2010)</td>
<td>3 prostate cancer</td>
<td>1050</td>
<td>1050</td>
<td>Prostate cancer</td>
<td>5</td>
</tr>
<tr>
<td>Escudier (2007)</td>
<td>3 renal cell cancer</td>
<td>649</td>
<td>641</td>
<td>Renal cell cancer</td>
<td>5</td>
</tr>
<tr>
<td>Rini (2010)</td>
<td>3 renal cell cancer</td>
<td>732</td>
<td>715</td>
<td>Renal cell cancer</td>
<td>5</td>
</tr>
</tbody>
</table>

NA, data not available; NSCLC, non–small cell lung cancer; The number of patients recruited for the original study; The number of patients actually exposed to the study drugs; The dose schedule was converted from a milligrams-per-kilogram schedule.

**Figure 1. Selection Process for RCTs Included in the meta-analysis.** A total of 213 potentially relevant studies of bevacizumab were identified, of which 159 were initially excluded for not meeting the inclusion criteria. An additional 32 trials were excluded for being duplicates, for having administering bevacizumab to both treatment and control groups, or not reporting adequate data for evaluation. Thus, 22 trials were selected for inclusion in the meta-analysis, including three phase 2 and 17 phase 3 studies.

**Figure 2. Begg’s Test Assessment of Publication bias for the Primary Endpoint of Relative Risk of (A) High-grade Neutropenia and (B) High-grade Febrile Neutropenia Events.** No evidence of publication bias was detected for the primary endpoint of this study.
to the inclusion criteria of each trial, patients were included in the analysis. The trials (n) covered a variety of underlying malignancies: breast cancer (n=4), colorectal cancer (n=2), mesothelioma (n=2), non-small cell lung cancer (n=3), ovarian cancer (n=1), pancreatic cancer (n=2), prostate cancer (n=1), and renal cell carcinoma (n=2). Five of the trials were phase II studies and 17 were phase III studies. In general, the baseline Eastern Cooperative Oncology Group status of patients was between 0 and 1. According to the inclusion criteria of each trial, patients were required to have adequate hepatic, renal, and hematologic functions. The exclusion criteria reported for the studies included the following conditions: significant cardiovascular disease, peripheral vascular disease, uncontrolled hypertension, serious non-healing wounds, major surgery within the previous 28 days, pre-existing bleeding diathesis, brain metastasis, regular use of aspirin (>325 mg/d) or nonsteroidal anti-inflammatory drugs, pregnancy or lactation, and current use of oral or parenteral anticoagulants, with the exception of prophylactic anticoagulants to maintain patency of vascular device access. In all trials, randomization had been performed between the control and bevacizumab groups. The bevacizumab doses were 2.5 or 5 mg/kg/week.

Patient characteristics

A total of 15056 patients from the 22 clinical trials were included in the analysis. The trials (n) covered a variety of underlying malignancies: breast cancer (n=5), colorectal cancer (n=4), gastric cancer (n=2), mesothelioma (n=2), non-small cell lung cancer (n=3), ovarian cancer (n=1), pancreatic cancer (n=2), prostate cancer (n=1), and renal cell carcinoma (n=2). Five of the trials were phase II studies and 17 were phase III studies. The trial characteristics are presented in Table 1.

In general, the baseline Eastern Cooperative Oncology Group status of patients was between 0 and 1. According to the inclusion criteria of each trial, patients were required to have adequate hepatic, renal, and hematologic functions. The exclusion criteria reported for the studies included the following conditions: significant cardiovascular disease, peripheral vascular disease, uncontrolled hypertension, serious non-healing wounds, major surgery within the previous 28 days, pre-existing bleeding diathesis, brain metastasis, regular use of aspirin (>325 mg/d) or nonsteroidal anti-inflammatory drugs, pregnancy or lactation, and current use of oral or parenteral anticoagulants, with the exception of prophylactic anticoagulants to maintain patency of vascular device access. In all trials, randomization had been performed between the control and bevacizumab groups. The bevacizumab doses were 2.5 or 5 mg/kg/week.

Incidence of neutropenic events

There were 2283 HGF events reported for 8350 patients who received bevacizumab (Table 2). The highest incidence (63.29%; 95% CI: 60.54%-65.96%) was observed in an ovarian cancer trial. The lowest incidence (7.26%; 95% CI: 5.51%-9.51%) was seen in the trials of Table 2. Incidence and Relative Risk of High Grade Neutropenia with Bevacizumab According to Dose, Tumor Type, and Chemotherapy Type

<table>
<thead>
<tr>
<th>Tumor type</th>
<th>No. of studies</th>
<th>Bevacizumab/Total</th>
<th>Control/Total</th>
<th>Incidence, % (95% CI)</th>
<th>RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>5</td>
<td>214/2163</td>
<td>85/1226</td>
<td>9.89 (8.70-11.23)</td>
<td>5.43 (2.07-13.49)</td>
</tr>
<tr>
<td>Colorectal</td>
<td>3</td>
<td>392/1512</td>
<td>143/1494</td>
<td>25.93 (23.78-28.20)</td>
<td>29.05 (26.80-31.40)</td>
</tr>
<tr>
<td>Gastric</td>
<td>2</td>
<td>148/439</td>
<td>155/432</td>
<td>33.83 (29.54-38.40)</td>
<td>35.96 (31.56-40.61)</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>2</td>
<td>36/100</td>
<td>41/102</td>
<td>36.22 (27.35-46.15)</td>
<td>40.2 (21.15-49.96)</td>
</tr>
<tr>
<td>NSCLC</td>
<td>3</td>
<td>366/1125</td>
<td>185/809</td>
<td>28.91 (19.77-40.17)</td>
<td>21.64 (12.36-35.10)</td>
</tr>
<tr>
<td>Ovarian</td>
<td>1</td>
<td>769/1215</td>
<td>347/601</td>
<td>63.29 (50.45-76.96)</td>
<td>57.74 (43.75-61.63)</td>
</tr>
<tr>
<td>Prostate</td>
<td>1</td>
<td>157/524</td>
<td>126/526</td>
<td>29.96 (26.19-34.02)</td>
<td>23.95 (20.52-27.79)</td>
</tr>
<tr>
<td>Pancreatic</td>
<td>2</td>
<td>153/573</td>
<td>125/550</td>
<td>26.54 (16.53-39.72)</td>
<td>22.51 (12.98-36.13)</td>
</tr>
<tr>
<td>Renal cell carcinoma</td>
<td>2</td>
<td>48/699</td>
<td>38/651</td>
<td>7.26 (5.51-9.51)</td>
<td>6.91 (5.07-9.37)</td>
</tr>
</tbody>
</table>

Table 3. Incidence and Relative Risk of High Grade Febrile Neutropenia with Bevacizumab According to Dose, Tumor Type, and Chemotherapy Type

<table>
<thead>
<tr>
<th>Tumor type</th>
<th>No. of studies</th>
<th>Bevacizumab/Total</th>
<th>Control/Total</th>
<th>Incidence, % (95% CI)</th>
<th>RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast</td>
<td>4</td>
<td>115/2139</td>
<td>39/1201</td>
<td>5.38 (4.50-6.42)</td>
<td>3.25 (2.38-4.41)</td>
</tr>
<tr>
<td>Colorectal</td>
<td>3</td>
<td>23/1592</td>
<td>29/1575</td>
<td>1.53 (1.02-2.29)</td>
<td>1.91 (1.33-2.74)</td>
</tr>
<tr>
<td>Gastric</td>
<td>2</td>
<td>32/439</td>
<td>29/432</td>
<td>7.29 (5.20-10.13)</td>
<td>6.71 (4.70-9.49)</td>
</tr>
<tr>
<td>Mesothelioma</td>
<td>2</td>
<td>3/100</td>
<td>2/102</td>
<td>3.11 (1.01-9.22)</td>
<td>1.97 (0.49-7.52)</td>
</tr>
<tr>
<td>NSCLC</td>
<td>3</td>
<td>36/1125</td>
<td>13/809</td>
<td>3.47 (1.53-7.66)</td>
<td>1.61 (0.94-2.75)</td>
</tr>
<tr>
<td>Ovarian</td>
<td>1</td>
<td>56/1215</td>
<td>21/601</td>
<td>4.61 (3.56-5.94)</td>
<td>3.49 (2.29-5.3)</td>
</tr>
<tr>
<td>Prostate</td>
<td>1</td>
<td>37/524</td>
<td>21/526</td>
<td>7.06 (5.16-9.59)</td>
<td>3.99 (2.62-6.05)</td>
</tr>
<tr>
<td>Pancreatic</td>
<td>1</td>
<td>3/296</td>
<td>1/287</td>
<td>1.01 (0.33-3.09)</td>
<td>0.35 (0.00-2.43)</td>
</tr>
<tr>
<td>Renal cell carcinoma</td>
<td>1</td>
<td>0/362</td>
<td>4/347</td>
<td>0.00 (0.00-2.43)</td>
<td>1.15 (0.43-3.03)</td>
</tr>
</tbody>
</table>

Dose

- Bevacizumab agents (5.0 mg)
  - 2.5 mg/kg/week: 5, 602/2090, 363/2057, 26.44 (20.84-32.92), 26.89 (19.64-35.64), 0.93 (0.85-1.01)
  - 5.0 mg/kg/week: 14, 1333/5102, 756/3776, 26.13 (24.94-27.35), 20.02 (18.78-21.33), 1.14 (1.07-1.21)
- Chemotherapeutic agents (5.0 mg)
  - Platinum or taxanes: 9, 1161/3152, 629/2303, 36.83 (35.17-38.53), 27.31 (25.53-29.17), 1.13 (1.06-1.22)
  - Non-platinum-taxanes: 5, 172/1950, 127/1473, 8.82 (7.64-10.16), 8.62 (7.29-10.17), 1.16 (0.95-1.43)
  - Overall: 21, 2283/8350, 1536/6391, 27.34 (26.40-28.31), 24.03 (23.00-25.10), 1.10 (1.02, 1.19)
The overall relative risk of developing HGN was greater in patients treated with bevacizumab (RR=1.10; 95% CI: 1.02-1.19; P=0.02). A moderate level of heterogeneity existed in these studies (P=0.09; I²=31%).

patients with renal cell cancer. Using a fixed-effects model, the summary incidence of HGF in patients receiving bevacizumab was 27.34% (95% CI: 26.40%-28.31%).

For HGFN, there were 305 events reported for 7792 patients, with the highest incidence seen in trials of patients with gastric cancer and the lowest incidence in trials of patients with renal cell cancer (Table 3). The summary incidence of HGFN in patients receiving bevacizumab was 3.91% (95% CI: 3.51%-4.37%).

Relative risk of neutropenic events

In order to assess the contribution of bevacizumab to the development of neutropenic events, including febrile neutropenia, we calculated the overall relative risk of HGN and HGFN. The overall RR of developing HGN in patients treated with bevacizumab versus those who did not receive bevacizumab was 1.10 (95% CI: 1.02-1.19; P=0.02) (Figure 3). A moderate level of heterogeneity existed in these studies (P=0.09; I²=31%). Similarly, the RR of high-grade febrile neutropenia was also significantly increased in bevacizumab-treated patients (RR=1.31; 95% CI: 1.08-1.59; P=0.005) (Figure 4); however, no significant heterogeneity was found among the included trials (Q=16.42; P=0.49; I²=0.0%).

Tumor type and risk of neutropenic events

To explore the relationship between tumor type and the risk of developing HGN and HGFN, we stratified patients by their underlying malignancy. RRs of HGN varied significantly by tumor type (P=0.005), suggesting that the association of bevacizumab with HGN may be different among these tumor types. In contrast, RRs of HGFN did not vary significantly by tumor type (P=0.16).

Bevacizumab dose and risk of neutropenic events

The two approved doses of bevacizumab are 2.5 mg/wk (low-dose) and 5.0 mg/wk (high-dose). Therefore, the RRs of HGN and HGFN with bevacizumab were determined for each bevacizumab dose. Among the clinical trials analyzed, data was available from five studies to calculate the RR of HGN in patients receiving low-dose bevacizumab and from 14 studies to calculate that in patients receiving the high-dose. The high-dose administration was found to be associated with a significantly increased risk of HGN (RR=1.14; 95% CI: 1.07-1.21; P=0.0001), while the low-dose administration showed no significant association with risk of HGN (RR=0.93; 95% CI: 0.85-1.02; P=0.14). Overall, a significant difference was found for the rate of HGN between the high- and low-doses of bevacizumab (P=0.006).

Five clinical trials provided data to calculate the RR of HGFN in patients receiving low-dose bevacizumab and 11 provided data to calculate that of high-dose bevacizumab. The high-dose administration was found to be associated with a significantly increased risk of HGFN (RR=1.55; 95% CI: 1.18-2.05; P=0.002). However, the low-dose administration was not found to be associated with an increased risk of HGFN (RR=0.94; 95% CI: 0.65-1.34; P=0.72). A significant difference was also found for the rate of HGFN between the high- and low-dose groups (P=0.03).

Concomitant chemotherapy regimen and risk of neutropenic events

Subgroup risk stratification analysis was carried out according to chemotherapy regimen (platinum- and taxane-based regimens versus non-platinum- and non-taxane-based regimens). Due to an inadequate number of low-dose trials for subgroup analysis, the RRs were only calculated for consistent high-dose administration of bevacizumab. Fourteen clinical trials provided data to calculate the RR of HGN and 11 provided data for calculation of that for HGFN. For HGN, the RR for bevacizumab with platinum- or taxane-based regimens was 1.13 (95% CI, 1.06-1.22), which was not significantly different from that for non-platinum- or non-taxane-based regimens (vs. RR=1.16; 95% CI, 0.95-1.43; P=0.81). Similar non-significant effects were observed for the risk of HGFN (P=0.69).

Discussion

Incidences of serious neutropenia, febrile neutropenia, and neutropenia-related infections have been reported as significantly increased in cancer patients treated with myelotoxic chemotherapy regimens plus bevacizumab, compared to patients treated with chemotherapy alone (Schutz et al., 2011). The results of our meta-analysis of 22 RCTs indicate that the risk of either HGN or HGFN was significantly increased in bevacizumab-treated patients (RR=1.31; 95% CI: 1.08–1.59; P=0.005). No significant heterogeneity was found among the included trials (Q=16.42; P=0.005) (Figure 3). A moderate level of heterogeneity was found among the included trials (Q=16.42; P=0.49; I²=0.0%).

In order to assess the contribution of bevacizumab to the development of neutropenic events, including febrile neutropenia, we calculated the overall relative risk of HGN and HGFN. The overall RR of developing HGN in patients treated with bevacizumab versus those who did not receive bevacizumab was 1.10 (95% CI: 1.02-1.19; P=0.02) (Figure 3). A moderate level of heterogeneity existed in these studies (P=0.09; I²=31%). Similarly, the RR of high-grade febrile neutropenia was also significantly increased in bevacizumab-treated patients (RR=1.31; 95% CI: 1.08-1.59; P=0.005) (Figure 4); however, no significant heterogeneity was found among the included trials (Q=16.42; P=0.49; I²=0.0%).

Tumor type and risk of neutropenic events

To explore the relationship between tumor type and the risk of developing HGN and HGFN, we stratified patients by their underlying malignancy. RRs of HGN varied significantly by tumor type (P=0.005), suggesting that the association of bevacizumab with HGN may be different among these tumor types. In contrast, RRs of HGFN did not vary significantly by tumor type (P=0.16).
significantly increased in bevacizumab-treated patients, compared to control patients. Given that neutropenic events are well-recognized major risk factors for the development of infections in cancer patients receiving chemotherapy (Aapro et al., 2006) the risk of neutropenia-related infections should be evaluated and prophylaxis medication should be considered for patients receiving bevacizumab therapy, especially when combined with chemotherapy.

Multiple mechanisms may be involved in the pathogenesis of bevacizumab-associated neutropenic events. It is possible that perturbed VEGF signaling may disrupt hematopoiesis in bevacizumab-treated patients. Inhibition of the VEGF receptor 1 (VEGFR1) has been shown to block hematopoietic stem cell cycling, differentiation, and recovery after bone marrow suppression (Rafii et al., 2003) Blockage of VEGFR1 or VEGFR2 signaling in mouse models was shown to inhibit the proliferation of hematopoietic progenitor cells and to impair repopulation of the hematopoietic compartment after myeloablation. When the mouse model was subjected to a combination of VEGF blockage and administration of cytotoxic drugs (including 5-fluorouracil, carboplatin and adriamycin), the risk of myelosuppression was increased and bone marrow recovery was delayed (Novitskiy et al., 2010) A meta-analysis performed by Schutz et al. (Schutz et al., 2011) indicated that sorafenib, a small molecule tyrosine kinase inhibitor targeting VEGFR, was also associated with an increased risk of neutropenia. Furthermore, PIGF, a member of the VEGF family, has been shown to restore hematopoiesis following bone marrow insult (Hattori et al., 2002; Rafii et al., 2003). Collectively, these data suggest that various forms of VEGF blockade, by inhibition of the receptors’ tyrosine-kinase domains or through antibodies targeting the VEGF ligand, may induce myelosuppression and delay bone marrow recovery.

Risk factors for neutropenic events associated with bevacizumab are currently poorly understood. We, therefore, evaluated the association of bevacizumab with neutropenic events according to tumor type, bevacizumab dose, and chemotherapeutic agent. Our results showed that the incidence of neutropenic events with bevacizumab varied significantly among different tumor types. The RRs of HGN with bevacizumab varied significantly by tumor types, although no significant difference was found in the RRs of HGFN by tumor types. These findings suggest that the underlying tumor biology or associated treatment might affect the incidence of neutropenic events (Ranpura et al., 2011).

The increased risk of bevacizumab-associated neutropenic events appears to be dose-dependent, as the relative risk of either HGN or HGFN was found to be greater in the high-dose group than in the low-dose group. This result suggests that blockade of VEGF signaling might induce dose-dependent myelosuppression or delayed bone marrow recovery. Considering that no significant association was found between the RRs of bevacizumab-associated neutropenic events and chemotherapy agent, the interaction between bevacizumab and the concomitant chemotherapy agent might be minor.

Our study has several limitations that should be taken into consideration when interpreting the results. First, the studies included in this meta-analysis were conducted at various institutions by different investigators with patients of different nationalities/ethnicities, and these differences may have biased the reported incidences. Second, these studies were conducted at academic centers and large institutions using patients with adequate major organ function, which might not reflect the patient population in other communities or patients with organ dysfunction. Finally, since this study was designed as a meta-analysis, confounding factors at the patient level could not be assessed properly or incorporated into the analysis.

In conclusion, our study has shown that bevacizumab is associated with an increased risk of either HGN or HGFN in cancer patients receiving concurrent chemotherapy. Furthermore, the increased risk of bevacizumab-associated neutropenic events is dose-dependent. These findings provide insights into the risk of neutropenic events that accompanies bevacizumab therapy. It is important for physicians and patients to recognize the risks associated with bevacizumab treatment so that serious neutropenic events may be detected early and resolved by altering the therapeutic regimen or other means.

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References


Okines AF, Langley R, Cafferty FH, et al (2010). Preliminary safety data from a randomized trial of perioperative epirubicin, cisplatin plus capecitabine (ECX) with or without bevacizumab (B) in patients (pts) with gastric or oesophagogastric junction (OGJ) adenocarcinoma. *J Clin Oncol*, 28, 4019 [meeting abstract].


