Introduction

Peritoneal metastasis (PM) is the most common, aggressive and lethal type of metastasis of gastric cancer (GC), in the era of standard D2 gastrectomy plus systemic chemotherapy, and has long been regarded as an incurable condition with rapidly deteriorating symptoms of refractory ascites, progressive intestinal obstruction, and uncontrollable abdominal pain (1).

Over the past four decades, significant improvements have been achieved in the field of peritoneal surface oncology. It is now generally accepted in the oncology community that in some highly selected patients peritoneal metastasis is a regional and treatable disease instead of a terminal disease (2). An integrated therapeutic package combining cytoreductive surgery (CRS) and perioperative intraperitoneal chemotherapy, including hyperthermic intraperitoneal chemotherapy (HIPEC), has been recommended as a preferred treatment option for some selected patients with GCPM. Intraperitoneal free cancer cells were recognized as the pathological cause of PM and the primary target for intraperitoneal chemotherapy. There were a lot of evidence demonstrating that HIPEC could effectively eradicate intraperitoneal free cancer cells and prolong overall survival in GCPM. However, there are still no standard HIPEC protocols. This review summarized the current HIPEC regimens used in GCPM from a literature search, trying to conclude the optimal HIPEC in GCPM, and indicate the future direction of HIPEC study. Moreover, the new data on the exploration of HIPEC in GCPM at Shijitan Hospital, Capital Medical University was shared. In conclusion, there was not enough evidence from publications and our own experience to conclude a recommended HIPEC regimen for GCPM. There is urgent need for standardizing HIPEC protocols worldwide. Accordingly, more international collaborations focusing on pharmacology and HIPEC-related parameters to generate high level evidence are essential.
intraperitoneal chemotherapy (HIPEC) has been developed to treat peritoneal surface malignancies, with curative or palliative intents (3).

Recently, the Chicago Consensus on the management of GCPM recommended CRS with gastrectomy and intraperitoneal chemotherapy as the treatment for synchronous GCPM with low peritoneal cancer index following by standard chemotherapy (4). However, the drug regimen, dose, temperature, duration and other parameters of HIPEC are still not standardized.

As an established center for peritoneal surface cancer in China, with the capacity of over 200 CRS + HIPEC procedures per year, our center has long been devoted to the development, application, promotion, and education on the integrated treatment of PM from gastrointestinal and gynecological malignancies. In this review, our goal is to update our exploration of optimal HIPEC in GCPM and summarize the current HIPEC strategies from a review of the literature, trying to identify the future direction of HIPEC study in GCPM. We present the following article in accordance with the Narrative Reporting Checklist (available at http://dx.doi.org/10.21037/jgo-20-262).

**Rationale for HIPEC in GCPM**

Intraperitoneal free cancer cells (IFCCs) originating from spontaneous exfoliation of the primary tumour or iatrogenic dissemination at the time of surgery are the pathological cause of GCPM (5). It has been described by Yonemura et al. that IFCCs could invade into peritoneum through transmesothelial and translymphatic pathways (6) (Figure 1). In other words, IFCCs and the resulting invisible micrometastasis on peritoneal surfaces are the primary target for preventing and treating GCPM.

The presence of plasma-peritoneal barrier makes the peritoneal cavity a relatively closed space lacking blood vessels and accounting for the poor effect of intravenous chemotherapy. HIPEC is designed to exploit the function of plasma-peritoneal barrier; that is to achieve a high intraperitoneal concentration of chemotherapeutics with a low plasma concentration. This positive gradient of chemotherapy in the peritoneum will intensify its direct antitumor effect with less systemic adverse effects. Hyperthermia itself has direct detrimental effects on IFCCs and also enhances the effects of intraperitoneal chemotherapy by increasing the depth of drug penetration and the drug uptake by tumor cells (5). We reported that HIPEC will effectively eradicate IFCCs in 78% patients with peritoneal metastasis. This was determined by detecting pre- and post-HIPEC viability of IFCCs using traditional cytological assessment. However, HIPEC failed to significantly reduce the molecular markers, like CEA mRNA and CK20 mRNA (Figure 2) (7).

**Role of HIPEC in GCPM**

It has been accepted that CRS+HIPEC is a promising integrated treatment strategy for GCPM (1). There is no doubt that CRS plays a fundamental role in this comprehensive package, and the completeness of CRS is the dominant independent prognostic factor for overall survival (OS). However, HIPEC is also an essential complement, rather than an alternative technique in the treatment of GCPM.

**Current HIPEC regimens in GCPM from a literature search**

The optimal methodology for HIPEC remains an unsolved problem. The multiple HIPEC regimens from 29 publications are listed in Table 2. We could conclude the following characteristics. First, 65% (17/26) centers preferred an open technique instead of closed technique, although there was no evidence to distinguish these two methods. Moreover, the open technique was more frequently used in Japan and China, while the closed technique was more common in USA. Second, a combined drug regimen was used more frequently than monochemotherapy. Mitomycin C in early years or more recently oxaliplatin nowadays has been used as a single
Figure 1 Mechanism of peritoneal metastasis from gastric cancer. Step 1: Cancer cell exfoliated from primary tumor, as a result of cancer invasion through serosa and/or iatrogenic dissemination during surgery. Step 2: Intraperitoneal free cancer cells (IFCCs) invade into subperitoneal space by directly interaction with mesothelium cells or through lymphatic orifices opening on peritoneal surface. Step 3: The integrity of the peritoneal-blood barrier is broken forming a favorable site for tumor proliferation. IFCCs colonize near the subperitoneal capillary, and proliferate via autocrine or paracrine stimulation by production of growth factors and neovascularization induced by angiogenic factors. The parallel pathologic image stained by HE method is shown on the right side. This figure was adapted from the original drawing of Yutaka Yonemura (6).

agent for HIPEC. The most common drug combination was cisplatin + mitomycin C ± etoposide and cisplatin + doxorubicin. Third, the dose of monochemotherapy with mitomycin C or oxaliplatin was relatively fixed. However, the dose of combined drugs varied widely. Fourth, there was no standard temperature and duration for HIPEC. The temperature of HIPEC in 29 publications ranged from 40 to 45 °C, and the duration ranged from 30 to 120 minutes. Fifth, the flow rate, carrier solution, and other parameters were not precisely discussed in these publications. Sixth, the HIPEC regimens were relatively conservative in Asia and USA, but quite aggressive in Europe. The multicenter studies in European countries showed that the HIPEC regimens varied widely from different centers even within the same country (8,39,40).

Exploration of HIPEC in GCPM at Shijitan Hospital

In 2011, our group published the first phase III RCT comparing CRS+HIPEC or CRS alone in GCPM. In this protocol we used the open-technique for HIPEC, with 120 mg of cisplatin and 30 mg of mitomycin C at 43.0±0.5 °C for 60−90 minutes (10). The trial showed that such HIPEC regimens could significantly improve survival with acceptable morbidity in synchronous GCPM patients.
Figure 2 Assessment of hyperthermic intraperitoneal chemotherapy (HIPEC) in treating intraperitoneal free cancer cells (IFCCs) by conventional cytology (A: IFCCs before HIPEC, B: IFCCs after HIPEC) and RT-PCR method (C: Agarose gel electrophoresis of the product of CEA and CK20, D: CEA mRNA value before and after HIPEC, E: CK20 mRNA value before and after HIPEC). Wright's stain, 1,000x, scale bar = 10 μm in A and B. Lane 1 is a DNA maker from 100 bp (bottom) to 600 bp (top); lanes 3 to 17 are the patients' samples; lane 2 is the positive control; lane 18 is the negative control in C. Horizontal lines represent mean ± standard error in D and E.
Thereafter, we tried lobaplatin + docetaxel combination in an open HIPEC technique. 50 mg/m² of lobaplatin and 60 mg/m² of docetaxel was each were dissolved in 3 L of normal saline. HIPEC was performed at 43.0±0.5 °C for 60 minutes. This regimen also showed efficacy and safety in GCPM patients (26).

However, we then changed our HIPEC regimen due to some non-medical reasons, like health economic disadvantage of lobaplatin, and short supply of mitomycin C. Lobaplatin was replaced by Cisplatin for HIPEC.

Recently, we retrospectively analyzed 125 GCPM patients treated with CRS+HIPEC at our center and investigated the impact of different HIPEC regimens on OS. The median OS for HIPEC-drug combination of cisplatin + docetaxel, lobaplatin + docetaxel, and cisplatin + mitomycin C was 12.4 (95% CI: 8.3−16.5) months, 10.9 (95% CI: 7.5−14.3) months, and 8.4 (95% CI: 3.6−13.1) months, respectively (P=0.073) (Figure 3A). Although, there was no significant difference among these three groups, the first two groups showed a better result in short term survival. In terms of temperature, the median OS was 10.7 (95% CI: 9.1−12.3) months in 43 °C-HIPEC group, significantly better than 9.3 (95% CI: 6.0−12.5) months in 42 °C-HIPEC group (P=0.030) (Figure 3B). In terms of duration, the median OS was 10.9 (95% CI: 7.3−14.5) months in 60-minute group, significantly better than 10.3 (95% CI: 8.1−12.4) months in 90-minute group (P=0.026) (Figure 3C). However, these factors showed no independently significant effect on OS.

**Conclusion**

Theoretically, CRS+HIPEC is designed as an integrated therapeutic package for peritoneal surface malignancies for cytologically radical resection and possible cure, with CRS for macroscopic resection of tumor nodules and HIPEC for microscopic eradication of IFCCs and micrometastasis. The recent PRODIGE 7 trial demonstrated an impressive advantage of complete CRS, but failed to verify the efficacy of HIPEC. This trial brings us a realization that we did not pay enough attention to HIPEC. It was discouraging that, we had not enough evidence from these publications and our own experience to conclude a recommended HIPEC regimen for GCPM. There is urgent need for standardizing HIPEC protocols worldwide. Accordingly, more international collaborations focusing on pharmacology and HIPEC-related parameters to generate high level evidence are essential.
Table 2 Hyperthermic intraperitoneal chemotherapy regimens in publications

<table>
<thead>
<tr>
<th>Reference</th>
<th>Nation</th>
<th>No.</th>
<th>HIPEC regimen</th>
<th>Technique</th>
<th>Drug &amp; dose</th>
<th>Temperature (°C)</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yonemura 1991 (16)</td>
<td>Japan</td>
<td>41</td>
<td>Open</td>
<td>CDDP 300 mg + MMC 50 mg</td>
<td>41–43</td>
<td>40–60</td>
<td></td>
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<tr>
<td>Yonemura 1996 (17)</td>
<td>Japan</td>
<td>83</td>
<td>Open</td>
<td>CDDP 300 mg + MMC 30 mg + VP-16 150 mg</td>
<td>42–43</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Fujimoto 1997 (15)</td>
<td>Japan</td>
<td>66</td>
<td>Closed</td>
<td>MMC 30–40 mg</td>
<td>44.5–45</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Hirose 1999 (14)</td>
<td>Japan</td>
<td>37</td>
<td>Open</td>
<td>CDDP 100 mg + MMC 20 mg + VP-16 100 mg</td>
<td>41.0–44.5</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Fujimura 2000 (18)</td>
<td>Japan</td>
<td>15</td>
<td>Open</td>
<td>CDDP 150–250 mg + MMC 60–100 mg + VP-16 120–200 mg</td>
<td>42–43</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Yonemura 2005 (19)</td>
<td>Japan</td>
<td>107</td>
<td>NR</td>
<td>CDDP 300 mg + MMC 30 mg + VP-16 150 mg</td>
<td>42–43</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Canbay 2014 (20)</td>
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<td>194</td>
<td>Open</td>
<td>DOC 30 mg/m²</td>
<td>NR</td>
<td>NR</td>
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</tr>
<tr>
<td>Yonemura 2020 (21)</td>
<td>Japan</td>
<td>255</td>
<td>Open</td>
<td>MMC 12.5 mg/m² + CDDP 50 mg/m²</td>
<td>42–43.5</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Hall 2004 (13)</td>
<td>USA</td>
<td>74</td>
<td>Closed</td>
<td>MMC 40 mg</td>
<td>40–41</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Shen 2009 (22)</td>
<td>USA</td>
<td>62</td>
<td>Closed</td>
<td>MMC 40 mg</td>
<td>40–42.5</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Magge 2014 (23)</td>
<td>USA</td>
<td>23</td>
<td>Closed</td>
<td>MMC 40 mg</td>
<td>42</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Rudloff 2014 (24)</td>
<td>USA</td>
<td>17</td>
<td>Closed</td>
<td>L-OHP 460 mg/m²</td>
<td>41</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Zhu 2006 (12)</td>
<td>China</td>
<td>22</td>
<td>NR</td>
<td>CDDP 250–300 mg + MMC 25–30 mg</td>
<td>43.0±1.0</td>
<td>60</td>
<td></td>
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<tr>
<td>Yang 2010 (25)</td>
<td>China</td>
<td>28</td>
<td>Open</td>
<td>HCPT 20 mg/CDDP 120 mg + MMC 30 mg</td>
<td>43</td>
<td>90–120</td>
<td></td>
</tr>
<tr>
<td>Yang 2011 (10)</td>
<td>China</td>
<td>68</td>
<td>Open</td>
<td>CDDP 120 mg + MMC 30 mg</td>
<td>43</td>
<td>60–90</td>
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<tr>
<td>Kang 2013 (11)</td>
<td>Taiwan, China</td>
<td>47</td>
<td>Open</td>
<td>CDDP 90–120 mg + MMC 30–40 mg + VP-16 60–80 mg</td>
<td>41–43</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Wu 2016 (26)</td>
<td>China</td>
<td>50</td>
<td>Open</td>
<td>LOB 50 mg/m² + DOC 60 mg/m²</td>
<td>43</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Tu 2016 (27)</td>
<td>China</td>
<td>231</td>
<td>Closed</td>
<td>5-FU 1,500 mg + CDDP 100 mg</td>
<td>43</td>
<td>60</td>
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<tr>
<td>Beaujard 2000 (28)</td>
<td>France</td>
<td>42</td>
<td>Closed</td>
<td>MMC 40–60 mg</td>
<td>45 [41–49]</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Glehen 2004 (29)</td>
<td>France</td>
<td>49</td>
<td>Closed</td>
<td>MMC 40–60 mg</td>
<td>43</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Scaringi 2008 (30)</td>
<td>France</td>
<td>26</td>
<td>Open</td>
<td>CDDP 200 mg/m² + MMC 120 mg</td>
<td>41–43</td>
<td>90–120</td>
<td></td>
</tr>
<tr>
<td>Glehen 2010 (31)</td>
<td>France</td>
<td>159</td>
<td>Open/ Closed</td>
<td>CDDP 50–100 mg/m² + MMC 30–50 mg/m² or L-OHP 360–460 mg/m² + CPT-11 100–200 mg/m²</td>
<td>40–43</td>
<td>60–120 or 30</td>
<td></td>
</tr>
<tr>
<td>Desantis 2015 (32)</td>
<td>France</td>
<td>14</td>
<td>Open</td>
<td>CDDP 50 mg/m²/L + DOX 15 mg/m²/L</td>
<td>43</td>
<td>60</td>
<td></td>
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<tr>
<td>Konigsrainer 2014 (33)</td>
<td>Germany</td>
<td>18</td>
<td>Open</td>
<td>CDDP 50 mg/m²</td>
<td>42</td>
<td>90</td>
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<tr>
<td>Boerner 2016 (9)</td>
<td>Germany</td>
<td>103</td>
<td>Closed</td>
<td>CDDP 75 mg/m² + DOX 15 mg/m²</td>
<td>42–43</td>
<td>90</td>
<td></td>
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<tr>
<td>Hultman 2013 (34)</td>
<td>Sweden</td>
<td>18</td>
<td>Open</td>
<td>CDDP 50 mg/m² + DOX 15 mg/m² or L-OHP 460 mg/m²</td>
<td>42–44</td>
<td>90 or 30</td>
<td></td>
</tr>
<tr>
<td>Yarema 2014 (35)</td>
<td>Ukraine</td>
<td>40</td>
<td>NR</td>
<td>CDDP 75 mg/m² + MMC 12.5 mg/m²</td>
<td>42.3±1.3</td>
<td>90</td>
<td></td>
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<tr>
<td>Muller 2014 (36)</td>
<td>Greece</td>
<td>26</td>
<td>Open</td>
<td>L-OHP 200 mg/m² + DOX 80 mg/m²</td>
<td>NR</td>
<td>NR</td>
<td></td>
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<tr>
<td>Caro 2018 (37)</td>
<td>Spain</td>
<td>35</td>
<td>Open</td>
<td>CDDP 100 mg/m² + DOX 15 mg/m²</td>
<td>42–43</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Reutovich 2019 (38)</td>
<td>Belarus</td>
<td>76</td>
<td>Closed</td>
<td>CDDP 50 mg/m² + DOX 50 mg/m²</td>
<td>42</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

MMC, mitomycin C; CDDP, cisplatin; VP-16, etoposide; L-OHP, oxaliplatin; HCPT, hydroxyacamptothecine; LOB, lobaplatin; DOC, docetaxel; 5-FU, 5-Fluorouracil; DOX, doxorubicin; CPT-11, irinotecan; NR, not reported.
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Footnote

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References


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