The role of interventional radiology in the management of hepatocellular carcinoma

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Conclusions

The existing data support the importance of a multidisciplinary approach in HCC management. Large randomized controlled studies are needed to provide clear indication guidelines for each method.

KEY WORDS

Interventional radiology, hepatocellular carcinoma, liver biopsy, ablation, embolization, drug-eluting beads

1. INTRODUCTION

Hepatocellular cancer (HCC) is the 2nd most frequent cause of cancer-related death in men and the 6th in women1. In 2008, the number of new liver cancer cases was estimated to be 748,300 worldwide, and 695,900 deaths were attributed to liver cancer that same year1.

Overall, liver transplantation, surgical resection, and locoregional therapies are the treatment options for HCC. However, only a small proportion of patients are suitable for the first two options2. A variety of image-guided interventions now play a vital role in the management of HCC. A multidisciplinary approach to those cases, with the involvement of interventional radiologists, became the main component in treatment success for patients with HCC.

This review summarizes and evaluates the role of the various available radiologic interventions in the management of HCC. A systemic search of PubMed, MEDLINE, Ovid Medline In-Process, and the Cochrane Database of Systematic Reviews using the key words “intervention,” “radiology,” “hepatocellular carcinoma,” “liver biopsy,” “ablation,” “embolization,” “chemo-embolization,” “radio-embolization,” “tissue banking,” or “drug-eluting beads” located all English-language scientific papers for retrieval and review. Cross-references and references from reviewed articles were also located and reviewed (Figure 1).
2. ROLE OF INTERVENTIONAL RADIOLOGY IN HCC

2.1 Diagnosis

To plan and assess treatment options, the treating team has to fully understand the pathology of HCC and its imaging characteristics. In 2010, the American Association for the Study of Liver Diseases based the diagnosis of HCC only on the typical enhancement pattern of the liver lesion in a single contrast-enhanced imaging procedure. Occasionally, liver biopsies are needed to diagnose HCC and, less frequently, to define prognosis after therapy based on tumour grade and microvascular invasion. The optimal liver biopsy for grading and staging a liver tumour is either 20–25 mm in length or consists of 11 complete portal tracts, or both.

There are two types of liver biopsy: needle core biopsy (NCB) and fine-needle aspiration (FNA). A NCB uses a large-gauge needle (1–3 mm in diameter) and retrieves a thin cylinder of liver tissue; FNA uses needles 0.4–0.6 mm in diameter. Recent studies indicated that the diagnostic value of these methods is comparable. With FNA, sensitivity is 67%–100%, and specificity is 98%–100%. The sensitivity of FNA depends mostly on the technique and skill of the radiologist and the cytopathologist. Accuracy with NCB is 62%–93%. A study found a 91.4% concordance between preoperative NCBs and final surgical specimens. However, NCB has an advantage over FNA in that the specimen obtained is suitable for an assessment of both architectural and cytologic features in addition to marker studies. One study showed that the respective diagnostic accuracies of 85.4% and 83% for FNA and NCB increased to 89.1% when both methods were used, and another found an accuracy increase to 88% from 78% with FNA and a similar accuracy with NCB.

The liver biopsy procedure is reported to carry the potential for a number of complications. Minor complications include pain and transient hypotension. Major complications include intrahepatic hemorrhage, intraperitoneal hemorrhage, hemothorax, pneumothorax, and injury of adjacent organs such as the pancreas, colon, gallbladder, or right kidney. Intrahepatic arteriovenous fistula can also occur after liver biopsy. The overall complication rate is 29%, with 90% of the complications being related to pain. Tumour seeding is another issue that has been reported in the literature, with a prevalence rate of 0.003%–5%. The mortality rate after liver biopsy is reported to be 0%–0.18%, mostly attributable to significant hemorrhage and bile peritonitis.

2.2 Treatment

In patients with early- or intermediate-stage disease, locoregional modalities play a pivotal role in the management of HCC by controlling disease progression until definitive therapy or by increasing eligibility for a curative treatment. In patients with advanced disease, the main aim of treatment is to control symptoms, prolong survival, and improve quality of life. A number of image-guided therapies are available (Table I), including direct ablation, portal vein embolization (PVE), transarterial embolization (TAE), transarterial chemoembolization (TACE), drug-eluting beads (DEBS), and transarterial radioembolization (TARE).

2.2.1 Ablative Therapy

Ablation involves the direct application of chemicals or thermal energy to the tumour to achieve necrosis. Two types of thermoablative therapy are available: hyperthermic [radiofrequency ablation (RFA), microwave ablation (MWA), and laser ablation] and hypothemic (cryotherapy). Chemical ablation uses percutaneous ethanol injection (PEI) or percutaneous acetic acid injection (PAI).
TABLE 1  Summary of interventional procedures used in hepatocellular carcinoma (HCC) management

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Aim</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portal vein embolization</td>
<td>Induce atrophy of embolized area and hypertrophy of contralateral lobe</td>
<td>Glue or alcohol and coil</td>
</tr>
<tr>
<td>Thermoablation</td>
<td>Induce destruction of tissue through thermal techniques</td>
<td>Radiofrequency ablation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laser ablation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Microwave ablation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cryotherapy</td>
</tr>
<tr>
<td>Chemoablation</td>
<td>Induce coagulative necrosis using chemotherapeutic cytotoxic effects</td>
<td>Percutaneous injection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of ethanol or acetic acid</td>
</tr>
<tr>
<td>Transarterial chemoembolization</td>
<td>Significant necrosis of tumour</td>
<td>Ethiodized oil plus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>any of various anticancer agents</td>
</tr>
<tr>
<td>Drug-eluting beads</td>
<td>Induce selective sustained release of chemotherapy over a long period of time</td>
<td>Polyvinyl alcohol hydrogel plus chemotherapy</td>
</tr>
<tr>
<td>Transarterial radioembolization</td>
<td>Cannulation of the hepatic artery with radiotherapy</td>
<td>$^{31}$I-Labelled ethiodized oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{90}$Y-Loaded microspheres</td>
</tr>
</tbody>
</table>

**Thermoablation Therapy:** Percutaneous thermal ablation is considered the best locoregional treatment option for focal unresectable early-stage HCC. The available techniques are based on controlling tissue damage by delivering energy to the lesion while minimizing collateral damage to healthy hepatic tissue and adjacent structures.

In RFA, a needle delivering high-frequency electrical current is introduced as a source of heat that causes cell death. The maximum temperature obtained and the duration of exposure to the heat affect the cell-kill zone, but a major limitation is the possibility of a heat-sink effect produced by large vessels near the ablation zone. The blood current can prevent complete necrosis of nearby tumour cells, potentially leading to positive margins. In some cases, the tumour’s arterial supply is emoblized in advance in an attempt to overcome the heat-sink effect.

The advantages of RFA include high local efficacy, sparing of normal-liver parenchyma outside the burn zone, and the potential for safe repetition multiple times. However, RFA puts the patient at a small risk of injury to structures within the burn zone and along the probe’s path of entry: pneumothorax, less than 1%; biliary injury, less than 1%; abscess, 1%; major hemorrhage, less than 1%; and tumour seeding, 1%. Nevertheless, the major complication rate of RFA ranges from 2.4% to 13.1% compared with a range of 9%–22% for surgical resection. Treatment of subcapsular tumours with RFA might require general anesthesia, because it can cause severe pain.

Salimi et al. reported a prospective study in which primary ablation after RFA was successful in 96% of patients, with local tumour progression rates of 4% and 14% at 1 and 5 years respectively, and survival rates of 92% at 1 year and 63% at 5 years. The size of ablated tumours in the study ranged between 1.2 cm and 3.5 cm.

Several studies aimed to evaluate the efficacy of RFA treatment in HCC patients, considering factors such as tumour size, location, and condition of surrounding liver parenchyma. A retrospective study showed no significant difference in the overall survival rate with surgical resection ($n = 2857$) and RFA ($n = 3022$) for HCC lesions 3 cm or less in size (2-year survival rate: 94.5% vs. 93%; $p = 0.64$). However, time to recurrence was significantly lower in the resection group than in the RFA group ($p = 0.0001$).

Livraghi et al. tested the efficacy of RFA in medium- and large-size HCC tumours. The trial included 80 tumours 3.1–5 cm in diameter and 46 tumours 5.1–9.5 cm in diameter. The authors reported a significant difference between the groups with respect to tumour necrosis: complete necrosis (defined as 100% necrosis) was found in 61% of medium-sized tumours and in 24% of large-sized tumours ($p = 0.001$).

In a retrospective study, Ng et al. evaluated RFA efficacy in 56 perivascular HCC tumours without hepatic inflow occlusion (tumour situated within 5 mm of a 1st- or 2nd-degree branch of the portal and hepatic veins). Those authors showed no significant difference between perivascular and non-perivascular HCC in terms of rates of complete ablation, local tumour progression, morbidity, and mortality. Their findings contrast with the results of a study by Lu et al. of 31 perivascular HCC tumours, which suggested that the efficacy of RFA is affected by the location of the tumour, which was also suggested in studies by McGahan et al. and Lounsberry et al..
Theories suggest that cirrhotic tissue could enable better thermal ablation through the "oven effect"50, which posits that the increased thickness of cirrhotic tissue around the nodule works as a thermal insulator, avoiding dispersion of the heat generated around the rfa electrode.

Microwave ablation works by changing the polarity of water molecules within tissues to generate heat. The frequency range used is usually between 915 MHz and 2.45 GHz51. Advantages of mwa include heating that is not limited by desiccation and charring51,52, eliminating the risk of skin burn caused by grounding pads51,53. In mwa, a larger ablation zone is created in a shorter time, meaning that tumours can be treated with fewer applicator insertions than are needed in rfa54. The effect of mwa on perivascular tumours is also better because of the lesser potential for a heat-sink effect51,55. The complication rate reported in mwa is 2.6%–7.5%, which includes the potential for ascites, pleural effusion, liver abscess, and perforation of adjacent organs54,56–58.

Lee et al.54 studied surgical mwa in tumours of 2–6 cm in diameter. All early postoperative computed tomography (ct) imaging showed no residual lesions; however, on follow-up, 42% of patients experienced local tumour progression. As Lee et al.54 noted, high local tumour progression is a downside of mwa and can be attributed to the use of a large applicator (5 mm in diameter), which increases the risk of tumour puncture and therefore tumour seeding.

**Cryoablation Therapy:** Ultralow temperature ablation uses argon gas to create tissue injury from temperatures that reach far below the freezing point. Cell death has been confirmed after reaching –20°C or after rapid freeze and slow thaw cycles at higher temperatures59.

Like rfa, cryoablation can be performed under conscious sedation, which makes it a good choice when the patient is a poor candidate for anesthesia60. The technique also has a lesser heat-sink effect than rfa. Cryoablation allows for real-time visualization of an “ice ball,” which permits precise evaluation of the ablated zone61,62 and maintains the cellular integrity of adjacent visceral linings63. Potential adverse effects include disseminated intravascular coagulation, coagulopathy, and multiorgan failure, which are signs of cryoshock syndrome, specific for cryotherapy in the liver64.

Median survival time (7.5 months vs. 3.2 months) and median time to progression (ttP) (3.5 months vs. 1.5 months) were found to be significantly different in cryotherapy and control groups65. Ultrasound-guided percutaneous cryotherapy proved to be effective and safe in patients with unresectable and recurrent hcc (mean tumour size: 2.8 ± 1.7 cm), with 1- and 3-year survival rates calculated to be 81.4% and 60.3% respectively. The disease-free survival rate was 67.6% and 20.8% at 1 and 3 years respectively66 (Table II).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study design</th>
<th>Intervention Patients</th>
<th>Characteristics</th>
<th>Median ttP (months)</th>
<th>Progression CR (% )</th>
<th>Survival 1-Year</th>
<th>Survival 3-Year</th>
<th>Survival 5-Year</th>
<th>P Value</th>
<th>Relevant details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmi et al., 2008</td>
<td>Prospective</td>
<td>Radiofrequency ablation</td>
<td>25</td>
<td>Single nodule &lt;3.5 cm or 4 nodule 3 or fewer nodules &lt;3 cm</td>
<td>14 (1 year)</td>
<td>96</td>
<td>92</td>
<td>65</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Chang et al., 2011</td>
<td>Cohort</td>
<td>Cryoablation</td>
<td>190</td>
<td>Advanced hcc related to hepatitis B</td>
<td>14 (3 years)</td>
<td>72</td>
<td>72</td>
<td>64</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Lee et al., 2012</td>
<td>Prospective</td>
<td>Microwave ablation</td>
<td>26</td>
<td>Mean tumour size: 3.8 cm (range: 2–6 cm)</td>
<td>14 (5 years)</td>
<td>65</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**ttP =** time to progression; **CR =** complete response.
In a recent meta-analysis comparing cryosurgery with RFA, RFA was found to be superior in terms of the local recurrence rate (odds ratio: 1.96; 95% confidence interval: 1.12 to 3.42)\(^7\). To our knowledge, no study has compared survival benefits for these techniques.

**Irreversible Electroporation:** Irreversible electroporation (IRE) is a new technology that has recently been applied in HCC treatment. It works by delivering pulses of electrical current up to 3 kV to tumour cells, producing an electrical field that creates nanopores in cell membranes. This irreversible damage affects homeostasis of the cell and causes cell death by apoptosis\(^68\). The two advantages of this technology are that it does not affect the extracellular matrix, thus maintaining structural integrity of the adjacent blood vessels and bile ducts\(^69\) and that it has no heat-sink effect\(^70\). Irreversible electroporation can therefore help in managing tumours in difficult locations. The technique also does not cause fibrosis and scarring after ablation, meaning that the treatment zone can be evaluated earlier than it can with other ablation methods\(^68\). However, IRE requires the patient to be under general anesthesia and deep neuromuscular block in both open and CT-guided percutaneous procedures\(^71\). The use of IRE in the management of HCC is still in its early stages, and no long-term results are available.

**Chemoablative Therapy:** Percutaneous ethanol injection is a well-established technique for treating HCC tumours less than 3 cm in size\(^33\). It is performed with a fine needle under imaging guidance\(^44\), and causes coagulative necrosis because of its cytotoxic effects (cytoplasmic dehydration, denaturation of protein, and small-vessel thrombosis)\(^33\). Because of cirrhotic margins around HCC tumours, the alcohol is relatively restricted to tumour tissue, sparing normal parenchyma\(^44\). Advantages of the procedure include a simple methodology, low cost, and safety\(^33\). With PEI, more than 4 sessions are required to treat each mass, even tumours smaller than 3 cm. Use of the technique is therefore more limited\(^72\) than for other modalities such as RFA, which needs fewer sessions for complete treatment\(^33,41\). Risks of hemorrhage, portal vein thrombosis, bowel necrosis, gallbladder injury, and liver necrosis have also been shown to increase with PEI\(^40\).

Tumour recurrence and survival rates for RFA, PEI, and PAI in the treatment of HCC 3 cm in size or less, Child–Pugh A and B, were compared in a randomized trial involving 187 patients. Radiofrequency ablation was found to be superior, with local recurrence rates at 1 and 3 years of 10% and 14%, compared with 16% and 34% in the PEI group and 14% and 31% in the PAI group. Survival rates at 1 and 3 years were 93% and 74%, 88% and 51%, and 90% and 53% in the RFA, PEI, and PAI groups respectively. Cancer-free survival rates at 1 and 3 years were 74% and 43% in the RFA group, 70% and 21% in the PEI group, and 71% and 23% in the PAI group. Large tumour size (>2 cm) and high tumour grade were independent factors that correlated with local recurrence\(^41\).

### 2.2.2 Embolization

**Venous Embolization:** Portal Vein Embolization: In a retrospective review of patients with HCC who underwent extended liver resection, portal vein embolization (PVE) was found to significantly increase the future liver remnant (FLR). Before surgical resection, PVE is used to induce progressive atrophy of the embolized territory and hypertrophy of the remaining non-tumour-containing parenchyma, allowing for safe extended liver resections\(^33\). This technique can be used when the FLR is less than 20%–30% of the initial total normal liver volume or less than 50% in fibrotic and cirrhotic livers\(^73–75\); however, the FLR gain is much less in cirrhotic patients than in those with mild or moderate fibrosis\(^73\).

Liquid agents (glue or alcohol) and small-particle embolization materials are used for distal embolization. Some groups also perform large central-vessel occlusion with coils\(^33\). Care must be taken not to deploy the coils too close to the hepatic hilum, because surgical ligation can then become more difficult. Observed PVE side effects include a transient increase in white blood cell count, fever, and abdominal discomfort\(^76\).

Siriwardana et al.\(^77\) prospectively studied the effect of PVE on HCC recurrence in 34 patients who underwent curative liver resection after PVE and in 102 who underwent resection without PVE. The use of PVE increased the FLR from 23% to 34%. The study concluded that PVE can increase the resectability rate of HCC tumours considered initially unresectable because of insufficient FLR and that PVE has no deleterious oncologic effect after major resection of HCC.

Simoneau et al.\(^78\) studied the effect of PVE on the growth of liver metastases from colorectal tumours. They prospectively followed tumour growth in 109 patients who underwent right PVE, and 11 who did not. Tumour growth was significantly different between the groups, with the tumour volume increasing by 33.4% in the right lobe and 49.9% in the left lobe of the liver of the embolized group and decreasing by 34.8% in the right lobe of the liver and by 33.2% in the left lobe of the non-embolized group (p < 0.001 in the right lobe, p = 0.022 in the left lobe)\(^78\). Despite those results, resectability was not affected. Similar data in HCC patients are lacking.

**Arterial Embolization:** TAE (Bland Embolization): In the hepatic arteries are occluded by injecting an intravascular substrate or by placing a device such as microspheres. The procedure is performed using a catheter under fluoroscopy.

Embolization is effective in the treatment of HCC primarily because HCC relies heavily on the arterial blood supply\(^44\). It is believed that intra-arterial administration of various drugs or devices allows...
for preferential distribution to tumours, and embo-
obilization of the feeding arteries results in ischemic
tumour necrosis79.

Nicolini et al.80 reported that TAE using micro-
pheres can achieve a complete response (CR), with
evidence of devascularization of the tumour in 89% of
cases. The definition of CR is an absence of pe-
ripheral enhancement in arterial-phase CT images.
However, the authors reported a local recurrence
rate of 62% and development of additional tumours
in 56% of patients. The time lag between assessment
of CR and local recurrence of the tumour ranged from
3 months to 6 months. Nicolini et al.80 suggested the
possibility of CT overestimation of tumour response
and the small study sample as potential explanations
for the high recurrence rate. Still, the study showed
that TAE is a well-tolerated procedure for patients
with early or intermediate HCC, causing no clinically
significant deterioration in liver function.

TACE: Combining embolization and administration
of cytotoxic medications, TACE is delivered to the
tumour by a transarterial route44. The first chemo-
embolic agent used was iodinated poppy seed oil81,
an excellent agent for intra-arterial embolization be-
cause of its viscosity and water insolubility. It causes
occlusion of the downstream capillaries, has a more
lethal effect on tumour cells than on hepatocytes, and
is radiopaque, which allows for radiologic visualiza-
during injection81,82. Iodinated poppy seed oil
can be used in combination with multiple anticancer
agents including cisplatin, doxorubicin, carboplatin,
epirubicin, mitoxantrone, and mitomycin C12. The
mixture is injected through a catheter placed into
the appropriate subsegmental branches of the hepatic
artery supplying the tumour33.

The role of TACE in neoadjuvant therapy is not
totally clear. A survival advantage might possibly
accrue from TACE administration before resection
(compared with resection alone)83; however, the tech-
ique is recommended as first-line palliative therapy
for nonsurgical cases with large or multifocal lesions
and no vascular invasion of distant metastases4,84.
Transarterial chemoembolization can also be used as
bridge therapy before transplantation, by downsizing
the tumour or controlling its growth33.

When TACE and systemic chemotherapy infu-
sion alone were compared in animal trials, TACE was
found to deliver a drug concentration 1–2 orders of
magnitude greater to the target organ and to maintain
a markedly longer dwell time85,86. Furthermore, it
reduced systemic toxicity because most of the drug
was retained in the liver87.

In a French multicentre trial of 127 patients with
advanced disease, survival rates in the TACE arm were
found to be 64% and 38% at 1 and 2 years, com-
pared with just 18% and 6% in matched untreated
controls88. In patients with Okuda stage 1 and 2
(but not Okuda stage 3) disease, the survival rate
was significantly increased after TACE than after no
therapy88 (Table III). A second trial89 compared the
mean survival rate in patients with HCC treated with
chemoembolization and in control patients treated
with symptomatic management: the difference was
significant at 2 years, with the former having a 54%
survival rate, and the latter, 26%.

Tumour response to TACE treatment is notably
affected by tumour size, TNM stage, preserved liver
function (Child–Pugh), and serum aspartate ami-
notransferase. Optimal TACE candidates are patients
with Child–Pugh A disease, with no extrahepatic
spread or vascular invasion (Barcelona Clinic liver
cancer stage B)90–92. Hepatic arterial infusion che-
motherapy might be a better choice in patients with
more advanced stage disease93.

Lee et al. compared TACE with surgical resection
in a large study94 in which 91 patients underwent
resection and 91 received multiple sessions of TACE.
The survival rate was significantly higher with liver
resection than with TACE (p = 0.0038), median sur-
vival time being 66 months and 37 months respec-
tively. However, the T3N0M0 subgroup of patients
showed no significant difference in survival rate
(5-year survival: 27% for resection vs. 23% for TACE,
p = 0.7512). However, there were significant differ-
ences in the basic characteristics of the two groups.
The resection group had older patients and a higher
number of patients who were positive for antibodies
to the hepatitis C virus, which might have negatively
affected their survival rate.

Contraindications to TACE are bilobar tumours
or total liver involvement exceeding 50%, Child–
Pugh C liver cirrhosis, distant metastasis, glomerular
filtration rate less than 40 mL/min/1.73 m², arterio-
portal fistula, or portal vein thrombosis95,96. In the
context of defective portal vein flow, the treated
zone might develop extensive necrosis because of block-
ing of the entire blood supply to that specific area97.
Its side effects are nausea, vomiting, possible renal
failure, cardiac toxicity, bone marrow aplasia, he-
patic abscess or cholecystitis, and post-embolization
syndrome (which occurs because of tumour necro-
sis and cytokine release). Manifestations of post-
embolization syndrome are fever, nausea, vomiting,
and right upper quadrant pain. It usually resolves
spontaneously in 48 hours98.

2.2.2 DEBs
Drug-eluting beads, which are made of polyvinyl al-
cohol hydrogel, provide selective, sustained release of
chemotherapy over long periods of time. Their action
is based on slow release into the body of doxorubicin
adsorbed to their surface. Initial results at follow-up
imaging have been positive, as evidenced by a lack
of enhancement in the tumour, which is indicative
of necrosis99. Beads come in various diameters; the
choice of proper bead size depends on vascularity and
the size of the lesion. Elution kinetics showed that
TABLE III  Okuda classification system for hepatocellular carcinoma (HCC)

<table>
<thead>
<tr>
<th>Okuda classification system</th>
<th>Tumour size&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Ascites</th>
<th>Bilirubin</th>
<th>Albumin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive (&lt;50%)</td>
<td>Negative (≥50%)</td>
<td>Positive (&gt;3 mg/dL)</td>
<td>Negative (&lt;3 mg/dL)</td>
</tr>
<tr>
<td>Stage 1</td>
<td>X</td>
<td>X</td>
<td>1 or 2 positive</td>
<td>X</td>
</tr>
<tr>
<td>Stage 2</td>
<td>X</td>
<td>X</td>
<td>3 or 4 positive</td>
<td>X</td>
</tr>
<tr>
<td>Stage 3</td>
<td>X</td>
<td>X</td>
<td>5 or 6 positive</td>
<td>X</td>
</tr>
</tbody>
</table>

larger beads release doxorubicin at a slower rate, and vice versa. The calculated half-life of doxorubicin-capable beads is 1730 hours for 700–900 μm beads and 150 hours for 100–300 μm beads. Compared with larger-diameter beads, smaller-diameter beads also cause a larger degree of pan-necrosis of the target lesion and adjacent liver tissue.<sup>99</sup>

Early studies of HCC response to DEB therapy revealed a 75% response rate at 6 months by the Response Evaluation Criteria in Solid Tumors, with 44.4% partial response (PR) and 25.9% stable disease (SD). Progressive disease was seen in 18.5% of patients, and the 1-year survival rate was 92.5%<sup>100</sup>. More recent evaluation demonstrated a 27% CR rate in patients by the Response Evaluation Criteria in Solid Tumors, with 13% PR and 3% SD. Progressive disease occurred in 40% of patients at 6 months’ follow-up. The overall survival rate was 93% at 6 months.<sup>101</sup> Boatta <i>et al.</i><sup>102</sup> reported a 42.9% CR rate in patients by the modified Response Evaluation Criteria in Solid Tumors (Table IV), with 29.8% PR, 17.5% SD, and just 9.7% progressive disease; however, the assessment occurred at 1 month of follow-up. The overall survival rate was 92.6% at 6 months.

A blinded randomized trial of 212 patients conducted by Lammer <i>et al.</i><sup>104</sup> compared disease control with DEBS and with TACE—“disease control” being defined as CR, PR, and SD combined. Tumour response was assessed on magnetic resonance imaging at 6 months by European Association for the Study of the Liver criteria (Table V). The disease control rates were 63.4% for DEBS and 51.9% for TACE, a difference that was not statistically significant. Patients with advanced disease (Child–Pugh B, Eastern Cooperative Oncology Group performance status 1, bilobar disease, and recurrent disease) experienced significantly better disease control and objective response rates with DEB treatment.<sup>104</sup>

With respect to the side effects of DEBS, Varela <i>et al.</i><sup>106</sup> reported PES in 10 of 27 patients, abdominal pain in 3 patients, mild fever in 6 patients, nausea and vomiting in 3 patients, and liver abscess in 2 patients.

### 2.2.4 Radioembolization

Radioembolization is a form of interstitial radiotherapy, which merges the interventional radiology technique of hepatic artery cannulation with radiotherapy. It delivers a high radiation dose to selected areas within the liver. The most frequently used compounds are 131I-labelled iodinated poppy seed oil and 90Y-loaded microspheres<sup>107</sup>. Treatment with 90Y in particular is associated with low toxicity.<sup>105</sup>

In a study investigating the long-term outcomes of TARE therapy in HCC patients, the response rate was found to be 57% after treatment with 90Y (based...
on size and tumour necrosis criteria); TTP was 7.9 months\textsuperscript{106}. A randomized controlled trial comparing \textsuperscript{131}I-labelled iodinated poppy seed oil TARE with best medical support in HCC patients having portal vein thrombosis showed a 6-month survival of 48\% with treatment; in the best medical support arm, there were no survivors at 6 months\textsuperscript{107}. Chaudhury et al.\textsuperscript{108} reported a case of CR for a 4.7-cm HCC tumour with vascular involvement treated using sorafenib and \textsuperscript{90}Y radioembolization.

Comparing TACE with TARE, Salem et al.\textsuperscript{109} observed no significant difference in survival time ($p = 0.42$); however, the difference in TTP was found to be clinically significant in favour of radioembolization (13.3 months for TARE vs. 8.4 for TACE, $p = 0.046$). When comparing \textsuperscript{131}I-labelled iodinated poppy seed oil TARE with conventional TACE for unresectable HCC, survival was similar for both treatments (6-month survival: 69.2\% vs. 65.6\%), but with fewer side effects in the TARE group\textsuperscript{110}.

Possible side effects of TARE include fatigue, nausea, vomiting, abdominal pain, and low-grade fever. Lymphopenia not associated with an increased risk of infection is also common. Compared with TACE, TARE is safe for use in patients with portal vein thrombosis	extsuperscript{111}, and a small study (12 patients) implied its safety in those with lobar or segmental biliary tract obstruction and normal bilirubin levels\textsuperscript{112,113}. However, non-targeted radiation can lead to "bystander organ injury" such as cholecystitis, gastrointestinal ulcers, and pneumonitis\textsuperscript{106,113–119}. For that reason, TARE procedures must be preceded by angiographic and scintigraphic mapping studies to evaluate the presence of shunts that might allow the radiosphere particles to bypass the liver and reach other organs. The shunts can then be embolized before therapy begins.

Compared with any other method for treating HCC, TARE has, to date, showed no clear survival benefit except for patients with portal vein thrombosis.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Suggested locoregional treatment in specific cases of hepatocellular carcinoma (HCC). PS = performance status; TARE = transarterial radioembolization; MWA = microwave ablation; RFA = radiofrequency ablation; DEB = drug-eluting beads; TACE = transarterial chemoembolization.}
\end{figure}
3. SUMMARY

After a thorough review of the literature, we suggest a flow chart (Figure 2) to prioritize the various locoregional treatment methods in specific cases of HCC. In early-stage disease (Child–Pugh A–B, with focal or 1–3 unresectable lesions), RFA tops all other thermoablative methods. In large tumours (up to 6 cm), MWA is preferred, and cryoablation is preferred in recurrent disease. Because of a lesser heat-sink effect, MWA and cryoablation are both preferred to RFA in perivascular disease. Chemoablation can be used in smaller lesions (<3 cm). In intermediate-stage, multifocal lesions (>3), TACE, DEBS, and TARE are to be used. In Child–Pugh A patients with T3N0M0 tumours, TACE is the method of choice. Drug-eluting beads are preferable in Child–Pugh B patients, with an Eastern Cooperative Oncology Group performance status 1 or bilobar or recurrent disease. In HCC cases with portal vein thrombosis, TARE is the method of choice.

The efficacy of our approach should be tested in a prospective manner. We believe that HCC patients should be managed in a multidisciplinary fashion.

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5. CONFLICT OF INTEREST DISCLOSURES

The authors have no financial conflicts of interest to declare.

6. REFERENCES

35. McGahan JP, Browning PD, Brock JM, Tesluk H. Hepatic
38. Gervais DA, Goldberg SN, Brown DB, Soulen MC, Millward
26. Stigliano R, Burroughs AK. Should we biopsy each liver mass
27. Huang GT, Sheu JC, Yang PM, Lee HS, Wang TH, Chen
22.  Stigliano R, Burroughs AK. Seeding following percutaneous


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