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REVIEW ARTICLE

Interventional oncology: A primer for clinicians on the role of ablation and embolization for solid tumors

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Abstract

Interventional radiology (IR) is a rapidly evolving medical field that combines advanced imaging with minimally invasive techniques for both diagnosis and treatment. Interventional oncology (IO), a subspecialty of IR, focuses on the minimally invasive, image-guided intervention for cancer and cancer-related conditions. IR plays an important and increasingly recognized role within the multidisciplinary care of patients with cancer, contributing meaningfully to diagnosis, therapy, and palliation. IO therapies, particularly tumor ablation and transarterial embolization, aim to target tumors directly while preserving surrounding healthy tissue. These therapies are increasingly supported by clinical guidelines and have shown favorable outcomes in cancers such as hepatocellular carcinoma, renal cell carcinoma, and metastatic colorectal cancer. This review focuses on the role of minimally invasive, image-guided, locoregional IR therapies for patients who have cancer.

KEYWORDS
ablation, embolization, interventional, oncology

INTRODUCTION

Interventional radiology (IR) has emerged as a pivotal field in modern medicine, integrating cutting-edge imaging technologies with minimally invasive techniques to manage several medical conditions. Over the past few decades, the scope of IR has expanded, now encompassing diagnostic and therapeutic interventions. These interventions are delivered under image guidance, such as computed tomography (CT), ultrasonography (US), magnetic resonance imaging (MRI), positron emission tomography (PET), and fluoroscopy using either trans-arterial or percutaneous approaches. In contrast to traditional surgical approaches, image-guided interventions are typically associated with minimal or no pain, lower complication rates, reduced hospitalization duration—often performed in outpatient settings—faster recovery times, and lower overall costs.[1,2]

Interventional oncology (IO) has emerged as a distinct IR subspecialty and plays a significant role in the multidisciplinary management of patients with cancer, from initial diagnosis to treatment to palliative care. Minimally invasive locoregional IR therapies have revolutionized treatment in patients with localized cancer, directly

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targeting tumors while preserving the surrounding healthy tissue. Of these therapies, ablation and transarterial embolization have gained widespread acceptance, offering excellent tumor control and improved survival outcomes.[1–3] Thermal ablation (TA) offers a percutaneous approach for achieving complete tumor eradication by directly applying energy to the tumor and, if applied correctly with adequate margins, could result in a durable response in the treated lesion. The choice of ablation modality (radiofrequency ablation [RFA], cryoablation [CA], or microwave ablation [MWA]) is physician-dependent and is affected by several factors, including national/international guidelines, tumor size, tumor location, risk of complications, peer-reviewed literature, and operator expertise and preference. Alternatively, transarterial embolization aims for targeted tumor control while minimizing systemic toxic effects by delivering plain microspheres (transarterial bland embolization [TAE]), chemotherapy-loaded microspheres (transarterial chemoembolization [TACE]) or radioactive microspheres (transarterial radioembolization [TARE]) directly to the tumor site through a catheter inserted into the blood vessels supplying the tumor.

Both ablative and transarterial therapies have demonstrated success in treating both primary and secondary malignancies, leading to their inclusion in major clinical guidelines for the management of primary and oligometastatic disease of certain malignancies, such as hepatocellular carcinoma (HCC), colorectal cancer, and kidney cancer, as summarized in Table 1. Optimal patient selection for these therapies is best done in the context of a multidisciplinary tumor board.

This review focuses on the role of minimally invasive, image-guided, locoregional IR therapies for patients with primary malignancies (HCC and renal cell carcinoma [RCC]) and oligometastatic disease (metastatic colorectal cancer, RCC, and sarcoma) as well as secondary bone cancer, highlighting the growing clinical acceptance of and guideline-based recommendations involving these interventions.

Given the limited availability of robust comparative evidence evaluating interventional oncologic therapies against focused radiotherapeutic modalities such as stereotactic body radiation therapy (SBRT), we have intentionally confined our discussion to IO-based approaches rather than attempting to comprehensively address all locoregional treatment options.

Renal cell carcinoma

Kidney cancer is the 10th most common cancer in the United States, accounting for approximately 5% of all cancer cases.[4] The incidence of newly diagnosed kidney cancer has been rising every year. Up to 67% of RCCs are identified incidentally as a small renal mass (<4 cm),[5] largely attributed to the widespread use of cross-sectional imaging. The emergence of minimally invasive, image-guided ablation therapy has led to a paradigm shift in the management of small renal masses. Percutaneous image-guided TA has emerged as a curative treatment option for small renal tumors because it provides excellent oncologic outcomes that are comparable to those of partial nephrectomy. In addition, percutaneous TA offers several advantages over surgery, including lower complication rates, enhanced preservation of kidney function, shorter hospitalizations, and quicker recovery.[6] TA is currently endorsed by multiple societal guidelines for the treatment of T1a RCC.[7–20]

Outcomes

Single-arm studies evaluating various ablation modalities in patients with T1a RCC have demonstrated favorable oncologic outcomes, with reported 5-year local recurrence-free survival rates of 92%–98%, metastasis-free survival rates of 94%–100%, and cancer-specific survival (CSS) rates up to 97%–100%.[6,17,21–26] Figure 1 illustrates long-term follow-up after TA for biopsy-proven RCC.

A comprehensive systematic review incorporating 107 studies evaluated the outcomes among patients undergoing radical nephrectomy (RN), partial nephrectomy (PN), or TA for the treatment of small renal tumors.[6] TA was associated with the most favorable perioperative outcomes profile, characterized by shorter hospitalizations, reduced intraoperative blood loss, and a lower rate of conversion to open surgery. Although local recurrence-free survival was reported to be lower with TA, patients who received more than one ablation treatment session had outcomes similar to surgery.[6] Although overall survival (OS) was lower in the TA cohort compared with both RN and PN, it likely reflects the selection bias inherent to treatment decision making because patients undergoing TA are typically older, have multiple comorbidities, and are often poor surgical candidates.[6] The CSS rate across all treatment modalities ranged from 95% to 100%, with no statistically significant differences observed between the groups. The metastasis-free survival rate was similarly high, ranging from 90.5% to 100%, and demonstrated comparable outcomes among all three treatment strategies.[6]

Similar findings were reported in Surveillance, Epidemiology, and End Results (SEER)-based studies comparing outcomes of TA versus PN or RN for T1a RCC.[27,28] In matched patient cohorts with similar baseline characteristics, Zhou et al.[27] identified a significant difference in the 5-year OS favoring the PN group compared with the TA group ($p = .0457$); however, no difference was observed in the CSS rate between both groups ($p = .4023$). Xing et al.[28] used the SEER database to evaluate the outcomes in patients with T1a RCC ($n = 10{,}218$) managed by PN, RN, TA, or active surveillance. In that report, although OS was higher for patients who underwent surgery compared with those who received TA, no significant difference was observed between both treatments when matched for age in a stratified analysis. However, the OS and CSS were superior in patients who underwent ablation compared with those under active surveillance.[28] In another SEER-based study, Uhlig et al.[29] associated both cryosurgery and TA with substantially higher CSS relative to active surveillance (cryosurgery: hazard ratio [HR], 0.25; 95% confidence interval [CI], 0.14–0.45; TA: HR, 0.27; 95% CI, 0.13–0.55).This is consistent with findings reported by Larcher and colleagues,[30] who

TABLE 1 Different clinical disease scenarios and recommended locoregional treatment.

Disease	Clinical scenario	Recommended locoregional treatment (with or without systemic therapy)
Renal cell carcinoma	<4 cm	Surgery or ablation
	>4 cm	Surgery; if not feasible, consider ablation
Hepatocellular carcinoma	Single lesion, tumors ≤3 cm	Surgery, ablation, TARE, or EBRT
	≤ 3 tumors, each ≤3 cm	Transplantation, resection, ablation, TARE, or EBRT if feasible
	Single lesion, tumors ≤8 cm	TARE or EBRT alone or bridging to surgery
	Multiple lesions, one or two segments	Radiation segmentectomy
	Multiple lesions, one lobe	Radiation lobectomy
Unresectable ontrahepatic cholangiocarcinoma	Single lesion, tumor ≤3 cm (unresectable)	Ablation; consider EBRT if ablation is not feasible
	≤3 tumors, each ≤3 cm (unresectable)	Ablation
	Single lesion, tumors >3 cm (unresectable)	Arterially directed therapies (TARE [preferred] or TACE or TAE) or EBRT
	Multiple lesions, one or two segments	Arterially directed therapies (TARE + radiation segmentectomy [preferred] or TACE or TAE)
	Multiple lesions one lobe or both lobes	Arterially directed therapies (TARE + radiation lobectomy [preferred] or TACE or TAE); consider hepatic arterial infusion chemotherapy (HAIC) if TARE/TACE is not an option
Oligometastatic disease		
RCC to	Bone, ≤5 lesions	Surgery or ablation or radiation therapy
	Lung, ≤5 lesions, each ≤3 cm	Surgery or ablation or radiation therapy
	Various organs, ≤5 lesions, each ≤3 cm	Surgery or ablation or radiation therapy
CRC to	Liver, ≤3 tumors, each ≤3 cm	Surgery equal to ablation
	Liver, >5 tumors (unresectable)	TARE alone or bridging to surgery
	Liver, single large lesion (unresectable)	TARE alone or bridging to Surgery or EBRT
	Liver, multiple lesions, one or two segments (unresectable)	TARE + radiation segmentectomy or radiation therapy
	Liver, multiple lesions, one lobe (unresectable)	TARE + radiation lobectomy
	Lung, ≤5 tumors, each ≤3 cm	Ablation or surgery
	Lung, ≤5 tumors (unresectable)	Ablation (equivalent to resection) or radiation therapy
	Lung, >5 tumors with one or two lesions not responding chemotherapy or immunotherapy	Ablation (equivalent to resection) or radiation therapy
Sarcoma to	Skeletal/soft tissue, ≤5 lesions	Ablation or radiation therapy
	Lung, ≤5 lesions, each ≤3 cm (unresectable)	Ablation or radiation therapy
	Various organs, ≤5 lesions, each ≤3 cm	Ablation or radiation therapy
	Liver, ≤5 tumors, each ≤3 cm	Ablation or surgery
	Liver, >5 tumors (unresectable)	Arterially directed therapy alone (TARE, TACE, or TAE) or bridging to surgery or radiation therapy
	Liver, single large lesion (unresectable)	Arterially directed therapy alone (TARE, TACE, or TAE) or bridging to surgery or radiation therapy
	Liver, multiple lesions, one or two segments (unresectable)	Arterially directed therapy (TARE + radiation segmentectomy or TACE or TAE) or radiation therapy
	Liver, multiple lesions, one lobe (unresectable)	Arterially directed therapy (TARE + radiation lobectomy or TACE or TAE) or radiation therapy

(Continues)

TABLE 1 (Continued)

Disease	Clinical scenario	Recommended locoregional treatment (with or without systemic therapy)
Bone metastases	≤5 tumors	Ablation or radiation therapy
	Painful skeletal lesions	Ablation or radiation therapy
	>5 tumors with one or two lesions, chemotherapy-resistant or immunotherapy-resistant	Ablation or radiation therapy

Abbreviations: CRC, colorectal carcinoma; EBRT, external-bema radiation therapy; RCC, renal cell carcinoma; TAE, transarterial bland embolization; TACE, transarterial chemoembolization; TARE, transarterial radioembolization.

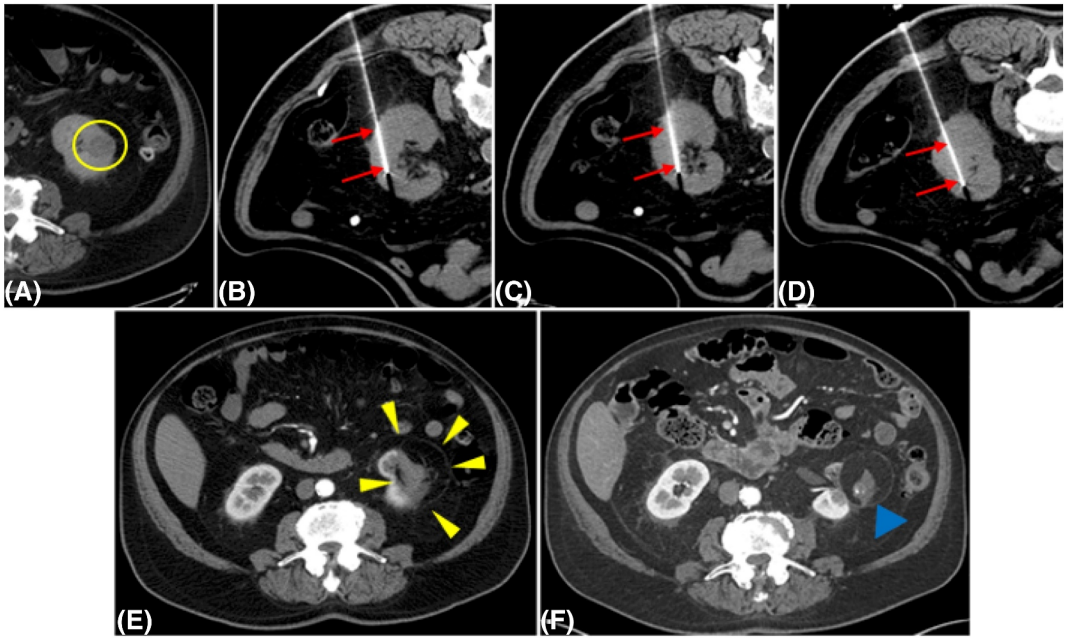

FIGURE 1 A man aged 75 years with biopsy-proven left clear cell renal cell carcinoma. (A) An axial CT image of the abdomen showed a low-density mass (yellow circle) in the left kidney. (B–D) Percutaneous radiofrequency ablation was performed using three probes (red arrows). (E,F) Contrast-enhanced CT scans at (E) 6 months and (F) 12 years after ablation showed no evidence of residual or recurrent disease (yellow and blue arrowheads). Gradual resorption and dystrophic calcification were present in the ablated area (blue arrowhead) on the contrast-enhanced CT image in F at 12 years after the ablation. CT indicates computed tomography.

shared their experience in a cohort of 1860 individuals diagnosed with clinical T1a RCC who underwent either percutaneous tumor ablation or active surveillance. In matched patient cohorts with similar baseline characteristics, those investigators demonstrated notably lower cancer-specific mortality in the ablation cohort compared with those managed through active surveillance alone (3.5% vs. 9.1%, respectively; HR, 0.47; 95% CI, 0.25–0.89).[30]

In terms of complication rates, several studies have reported a lower overall complication rate associated with TA compared with surgical interventions. Talenfeld et al.[31] conducted a population-based analysis comparing outcomes of TA, PN, and RN in patients aged 66 and older with T1a RCC. Those authors observed that TA was associated with lower rates of 30-day non-urological complications compared with PN and RN (6% vs. 29% and 30%, respectively). In addition, patients who received TA experienced fewer instances of acute renal failure (3%) compared with those who received PN (7%) and RN (11%). Within 1 year after treatment, the incidence of new-onset chronic renal insufficiency was lower in the TA group (11%) than in the RN group (18%) and was comparable to that in the PN group (9%). Similar results were reported by Katsanos et al.,[32] who evaluated six clinical trials involving 587 patients with small renal tumors, comparing TA versus surgical nephrectomy. Their evaluation indicated that TA was associated with a significantly lower overall complication rate (7.4% vs. 11%; $p = .04$) and a smaller postoperative decline in the estimated glomerular filtration rate (mean difference, −14.6 mL per minute per 1.73 m^2; $p = .03$) compared with nephrectomy. In that systematic review, the local recurrence rates and disease-free survival (DFS) up to 5 years were similar between the two groups, suggesting that TA offers comparable oncologic outcomes with reduced morbidity and better preservation of kidney function.[32] These findings support that TA offers a less invasive alternative with reduced perioperative risks and better preservation of renal function, and it is particularly beneficial for older patients.[31]

Position in clinical guidelines

As supported by multiple societal guidelines, TA is an effective treatment for renal tumors measuring up to 4 cm.[7–9] Furthermore, TA is an excellent treatment choice for patients with multiple renal tumors or compromised renal function (such as renal insufficiency or a solitary kidney), patients with genetic predispositions or syndromes (such as von Hippel–Lindau disease), and patients who refuse surgery.[7,8,10–17] Contemporary studies have explored TA as a treatment option for select T1b lesions (4–7 cm).[18–20] Figure 2 illustrates different clinical RCC scenarios and recommended treatment.

Hepatocellular carcinoma

HCC is the third-leading cause of cancer-related mortality worldwide and the leading cause of death in patients with cirrhosis.[33,34] In general, liver-directed therapies should be considered in patients who have primary liver malignancies without extrahepatic disease.[35–44]

Outcomes

Thermal ablation

When stage A HCC is treated with TA, the complete response rate ranges from 70% to 90%, with a median OS of approximately 60 months.[45] These favorable outcomes position TA as a curative therapy for small (<3 cm) HCC.

Prospective RCTs, such as the SURF-RCT trial, have demonstrated comparable results for RFA compared with surgical resection (SR) in patients with small HCCs, defined as three or fewer nodules, each measuring ≤3 cm in greatest dimension, with a 5-year OS rate of 74.6% in the SR group versus 70.4% in the RFA group ($p = .84$), whereas the 5-year RFS rate was 42.9% for the SR group versus 42.7% for the RFA group ($p = .84$). Serious adverse events occurred in 3.3% of surgical patients and in no patients in the RFA group.[46] In a systematic review and meta-analysis of eight randomized controlled trials (RCTs) comparing RFA versus SR, Jia et al. reported no statistically significant differences in OS or DFS between the two modalities. However, RFA demonstrated a significantly lower complication rate (odds ratio, 0.65; 95% CI, 0.44–0.80; $p < .05$) along with advantages in terms of reduced hospital stay, lower postintervention mortality, and decreased health care costs.[47]

In recent years, MWA has been increasingly adopted over RFA across numerous institutions because of several distinct advantages, including the ability to achieve larger ablation zones, facilitating the achievement of adequate ablative margins, which are essential for effective local tumor control. Moreover, technological advancements—such as the development of dedicated software to assess the adequacy of ablative margins—have reduced rates of local tumor progression, a key prognostic indicator of clinical outcomes.[48,49] A meta-analysis that included 16 studies ($n = 2622$) comparing MWA versus SR in patients with HCC and liver metastases indicated that OS was similar between the two modalities.[50] Moreover, MWA was associated with reduced complication rates, decreased intraoperative blood loss, shorter procedure duration, and a reduced hospitalization period.[50] Although these findings are promising, further randomized studies are necessary to compare SR and modern TA techniques in patients with early stage HCC.

Intra-arterial therapies: TARE, TACE, and TAE

For patients with early stage to intermediate-stage HCC who are not candidates for liver transplantation, SR, or TA, intra-arterial therapies like TARE, TACE, and TAE are great options. There is consensus among the IR community that TARE can result in superior outcomes compared with TACE and TAE, which is based on several RCTs, including the PREMIER and TRACE trials. The PREMIERE trial[51] randomized patients who had unresectable, unablatable HCC to undergo TARE or conventional TACE and reported a significantly longer time to progression with TARE (>26 vs. 6.8 months), although OS was similar when censoring for transplantation. The TRACE trial[52] compared TARE versus drug-eluting bead–TACE mostly patients with intermediate-stage HCC and demonstrated both superior time to progression (17.1 vs. 9.5 months) and OS (30.2 vs. 15.6 months) for TARE, with comparable safety profiles. Together, these trials suggest that TARE offers more durable tumor control than TACE, with evidence for improved survival in some patients.[51,52] There are also randomized data suggesting comparable results with TACE and TAE. For example, a randomized, single-center trial[53] compared doxorubicin-eluting microsphere TACE with bland microsphere embolization in patients with unresectable HCC. That study

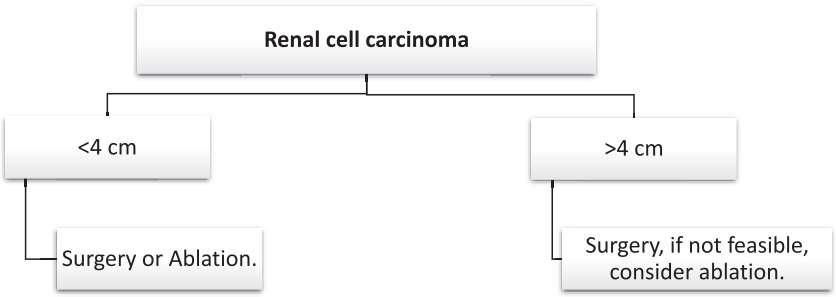

FIGURE 2 Illustration of recommended locoregional therapies for T1 renal cell carcinoma.

demonstrated no significant difference in progression-free survival (PFS) or OS between the two groups. Specifically, the median PFS was 6.1 months for TACE and 5.4 months for bland embolization (HR, 1.02; 95% CI, 0.69–1.51), whereas the median OS was 15.1 months for TACE and 14.6 months for bland embolization (HR, 1.05; 95% CI, 0.71–1.55). These findings suggest that the addition of chemotherapy to the embolic procedure did not confer a clear clinical benefit over bland embolization alone.

For patients with early stage HCC, contemporary studies using TARE have demonstrated a greater than 80% objective response rate with a mean duration of response of 6 months and longer.[40,54] The retrospective LEGACY study included patients ($n = 162$) with solitary HCC <8 cm who were treated with TARE and reported an objective response rate of 88% and a median duration of response of 11.8 months.[40] The localized PFS rate was 93.9% at 2 years. Grade 3 adverse events occurred in 19% of patients, but most resolved during the study. Despite great results, the study had several limitations, including a retrospective design and the limited number of patients available for follow-up after 3 years. In a prospective study that included 30 patients with three or fewer tumors who received TARE, Kokabi et al. reported an objective response rate of 81% at 6 months and a median duration of response of 32.7 months.[54] More recently, the Doorway prospective multicenter clinical trial evaluating the role of yttrium-90 (^{90}Y) radioembolization in patients with HCC (Barcelona Clinic Liver Cancer [BCLC] stage 0–B) have completed recruitment, and results will be available in the next few months. These results could help verify the results of the LEGACY study in a prospective, independent manner.[55] Figure 3 provides images from a patient with HCC who was treated by selective ^{90}Y treatment and had a sustained complete response on follow-up at 2 years.

For patients with BCLC stage B HCC (multifocal HCC and no evidence of vascular invasion or extrahepatic dissemination with preserved liver function and a performance status of 0–2), TARE is preferred over TACE because studies have demonstrated that TARE is associated with a longer time to progression after treatment.[51] However, most patients with BCLC B disease do not qualify for curative-intent TARE. Only select patients with BCLC stage B disease may be candidates for curative-intent TARE, such as those with disease confined to a lobe or with enough unaffected liver parenchyma to support high-dose ablative TARE to the diseased liver. In the prospective, randomized TRACE study, 72 patients with unresectable HCC were assigned to TARE or TACE. Those in the TARE arm achieved a longer median time to progression (17.1 vs. 9.5 months; $p = .002$) and median OS (30.2 vs. 15.6 months; $p = .006$).[52]

For patients with BCLC stage C HCC (HCC with vascular invasion or extrahepatic spread and a performance status ≤2) in whom systemic therapy is the standard of care, TARE can be offered as a consolidative option to those with good underlying liver function who achieve disease control. Although there is no consensus regarding treatment for these patients, three separate prospective studies have demonstrated good outcomes after TARE monotherapy even in the presence of portal vein tumor thrombus, with OS ranging from 13 to 15 months.[56–58] In patients with HCC who are refractory to or unsuitable for other locoregional therapies, the Radiation Therapy Oncology Group RTOG-1112 phase 3 RCT demonstrated a benefit of combining SBRT with sorafenib in improving OS and PFS after adjusting for stratification

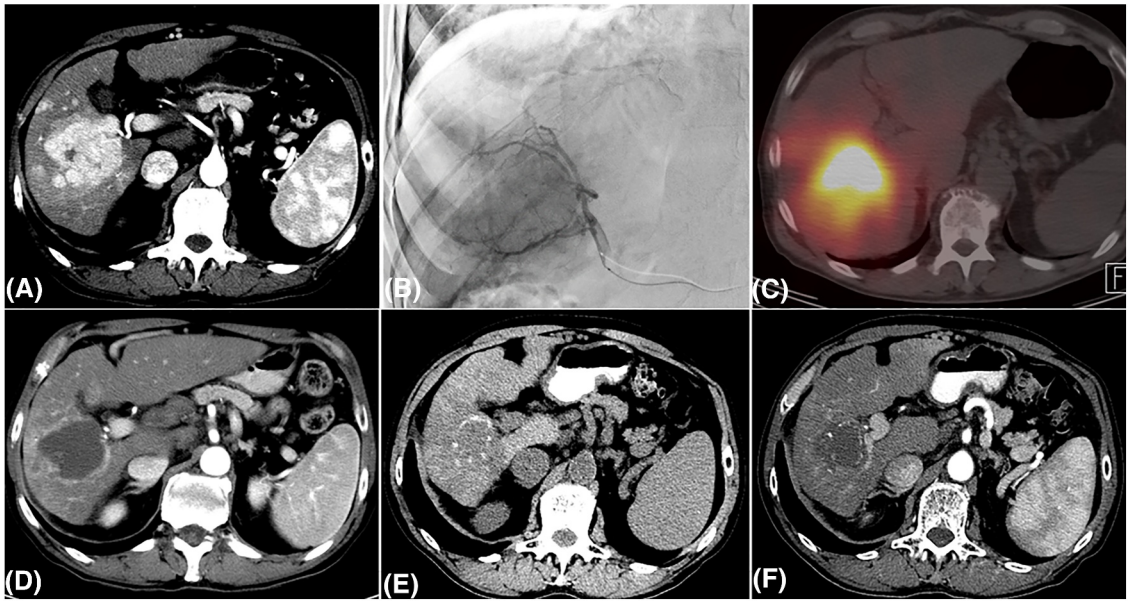

FIGURE 3 A man aged 64 years with HCC treated with TARE. (A) Contrast-enhanced CT showed a 7-cm HCC with satellite nodules. (B) Digital subtraction angiography demonstrated multiple feeding vessels connected to the tumors. (C) A posttreatment, single-photon emission CT confirmed microsphere deposition in the tumor. (D) Contrast-enhanced CT at 6 months after TARE showed the tumor had a complete response to TARE. (E) Noncontrast and (F) contrast-enhanced follow-up CT scans at 2 years demonstrated areas of calcification within the treated tumor with no evidence of residual or recurrent disease. CT indicates computed tomography; HCC hepatocellular carcinoma; TARE, transarterial radioembolization.

factors (OS, 15.8 vs. 12.3 months; PFS, 9.2 vs. 5.5 months for sorafenib combined with SBRT vs. sorafenib alone, respectively).[59]

Combination locoregional approaches

It is also common to combine multiple locoregional approaches when a patient's disease status (number, size, and distribution of the lesions) is not conducive to a single type of locoregional therapy. For example, in select patients who have multifocal disease with a higher disease burden in one lobe, combining lobar TARE or TACE with TA or SBRT in the contralateral lobe sometimes may result in achieving great local control. All of these cases have to be reviewed in a multidisciplinary tumor board to achieve consensus with different specialties, such as surgical oncology, radiation oncology, medical oncology, and IR, before proceeding.

In addition, there is evidence suggesting better outcomes when intra-arterial therapies like TACE are combined with an ablative therapy such as TA or SBRT to treat single lesions. For example, a retrospective study in a cohort of 289 patients with HCC demonstrated that the addition of ablation (TA or SBRT) significantly improved outcomes: the 3-year OS rate was 85.3% with combination therapy versus 47.1% with TACE alone, and the median OS nearly doubled (83.4 vs. 33.9 months). The study concluded that adding ablative therapy after TACE was associated with markedly improved local control and survival.[60]

In summary, percutaneous TA is a safe and effective treatment option for patients with small HCC. Growing evidence continues to support its efficacy, establishing it as a curative alternative for appropriately selected patients. For larger lesions, TARE with appropriate advanced dosimetry provides excellent local tumor control, improves OS compared with TACE, and is potentially curative in select patients. Figure 4 provides different clinical HCC scenarios and recommended locoregional treatment.

Position in clinical guidelines

Percutaneous liver ablation is widely recognized in clinical practice as a treatment for liver malignancies, offering faster recovery and lower costs than conventional SR.[35] According to the 2022 BCLC treatment guidelines, ablation with RFA or MWA is the recommended approach to first-line treatment for patients with very early stage HCC (defined as a solitary tumor ≤2 cm) who are not candidates for liver transplantation or SR.[36] Ablation is also an alternative option for patients with early stage HCC who are unsuitable for SR because of portal hypertension or liver dysfunction, provided that they have no more than three tumors and that each is no larger than 3 cm in greatest dimension.[36,37] Candidates for liver ablation should have Child–Pugh class A or B liver function status and a good performance status.[38] Given its lower invasiveness and cost, ablation may be prioritized in appropriate candidates, whereas SR may be preferred for larger tumors or tumors located in high-risk areas for ablation, such as near the gall bladder.

For patients who are not candidates for transplantation, SR, or ablation, the 2022 BCLC guidelines recommend TACE and TARE (or selective internal radiation therapy) for stage 0–A disease (up to three tumors, each <3 cm in greatest dimension), for tumors that require downstaging, or for patients awaiting liver transplantation.[36,39] 2025 European Association for Study of the Liver guidelines for the treatment of HCC has released a more flexible approach for these patients and consider external-beam radiation therapy as an option for patients who have a single lesion within Milan criteria when there is a significant risk of recurrence after treatment (greatest tumor dimension >3 cm), or based on location, or as an alternative to TARE/TACE in patients who are unsuitable for or experience recurrence after ablation and are at high risk for complications from TACE/TARE (such as colonized biliary tree, increasing the risk of infection, and liver abscess after TACE/TARE).[61] Once known as only a palliative treatment option, TARE is also a potentially definitive treatment for select patients. Curative-intent radioembolization refers to ^{90}Y segmentectomy or lobectomy in selected patients with localized HCC (BCLC stage 0–A and select BCLC stage B amenable to ^{90}Y segmentectomy), delivered at higher intensity versus palliative ^{90}Y with the primary aim of achieving complete and durable tumor eradication, analogous to SR or ablation, rather than

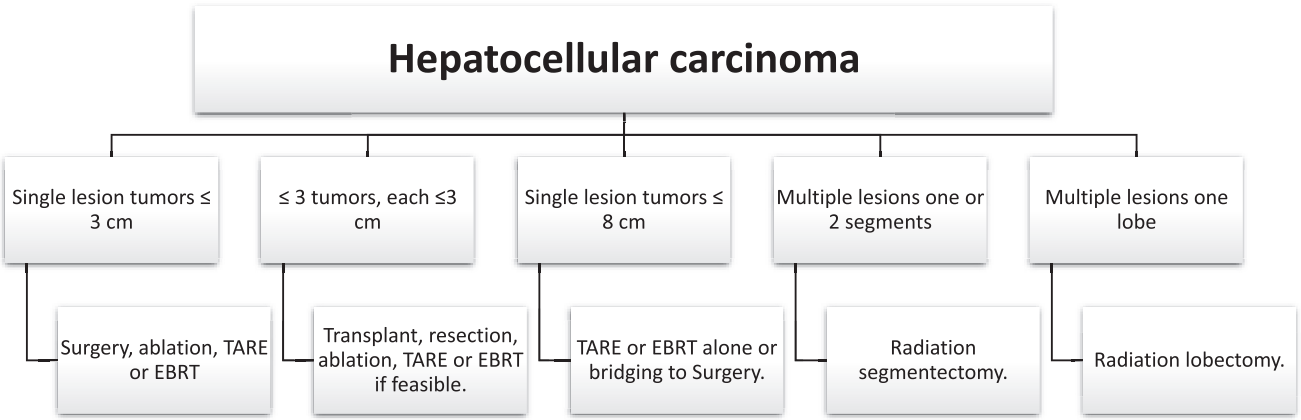

FIGURE 4 Illustration of recommended locoregional therapies (with or without systemic therapy) for hepatocellular carcinoma. EBRT indicates external-beam radiation therapy; TARE, transarterial radioembolization.

palliation, bridging, or downstaging. The curative-intent ^{90}Y approach can also be applied to patients with other malignancies, such as intrahepatic cholangiocarcinoma (iCCA), colorectal liver metastasis (CLM), or other tumors with liver metastasis that are amenable ^{90}Y segmentectomy, to achieve complete and durable tumor responses in the treated lesion. This curative potential is thanks to the progress made in the application of advanced dosimetry (calculating the radiation dose for treatment), with proven efficacy in randomized prospective trials, such as the Dosisphere trial-01,[62] and supported by post-TARE pathologic data from liver explants confirming a complete pathologic response.[40] Today, TARE has been broadly adopted to treat primary liver tumors, mainly HCC.[41,42]

TARE can also be used palliatively to improve PFS or hepatic PFS. In these patients, the use of advanced dosimetry techniques (maximizing the radiation dose to tumor and minimizing it to the normal liver) is mandatory for proper patient selection and treatment.[43] In prospective studies, approximately 10%–15% of patients in the palliative setting are not eligible for such treatment because of dose constraints.[43,44]

Intrahepatic cholangiocarcinoma

Cholangiocarcinoma encompasses a heterogeneous group of malignancies arising from the biliary epithelium. It represents the second most common primary hepatic malignancy, accounting for approximately 15% of liver cancers and 3% of all gastrointestinal cancers.[63,64] Based on anatomic location, it is classified into intrahepatic, perihilar, and distal cholangiocarcinoma.[64,65] Although systemic therapies remain central to the management of cholangiocarcinoma, growing evidence supports the role of TA in iCCA management, which aims to maximize local tumor control while preserving liver parenchyma.[66,67]

Outcomes

TA has demonstrated efficacy for patients with small iCCAs, resulting in outcomes comparable to those achieved with SR.[68–72] A multicenter cohort study published by Pang et al. compared MWA with SR for treating primary iCCA.[68] The study included 944 patients from 10 tertiary hospitals who were seen between 2009 and 2022 and had a median follow-up of 4.7 years. In matched patient cohorts with similar baseline characteristics, compared with SR, MWA demonstrated comparable OS (5-year OS: 44.8% vs. 40.4% with SR; $p = .761$) and DFS (37.3% vs. 40.8%; $p = .129$). Notably, DFS in patients who underwent MWA has improved since at least 2017, demonstrating a narrowing gap in survival outcomes compared with SR. Those authors reported that achieving an ablative margin ≥5 mm was crucial to survival; when patients who underwent either MWA or SR achieved this margin, DFS was similar. MWA offered advantages in perioperative outcomes, including shorter operation time, reduced blood loss, and lower complication rates. Therefore, MWA could be a viable alternative to SR for patients who have early stage iCCA, especially those who are unsuitable for surgery, provided an adequate ablative margin is achieved.[68]

In TA, margin width is a critical determinant of local tumor progression. However, no consensus exists regarding the optimal minimal ablative margin in iCCA. Therefore, many advocate for larger safety margins (an ablation zone extending beyond tumor margins) because of the tumor's infiltrative nature.[71] Data from the COVER-ALL randomized clinical trial (6% of volunteers had iCCA) validated the intraprocedural use of software-based ablation confirmation methods for minimal ablative margin assessment during liver tumor ablation. In that trial, with adequate safety margins, none of the patients with iCCA experienced progression.[49]

Locoregional, arterially directed therapies have also shown promise in patients with unresectable iCCA.[67] Given the rarity of iCCA, none of these treatment approaches have been evaluated in RCTs.[67] The MISPHEC trial demonstrated the efficacy and safety of combination systemic therapy and ^{90}Y in the first-line setting and the ability to downstage patients to render them candidates for SR.[73] In this selected population, the median PFS was 14 months, and the median OS was 22 months. In addition, in nonsurgical candidates, when the disease is anatomically confined to a few segments or a lobe, TARE radiation segmentectomy or ablative radiation lobectomy provides excellent local control. In the case of widespread disease, studies have demonstrated that using advanced dosimetry techniques significantly improves OS compared with older dosimetry techniques[74,75]

In summary, the role of locoregional therapies in iCCA treatment is expanding, with early data showing improved oncologic outcomes. TA has emerged as a potential curative option for selected, small iCCAs, offering survival outcomes comparable to those achieved by resection, with a favorable safety profile. Further large-scale studies are warranted to refine optimal minimal ablative margin thresholds in iCCA and to continue improving local tumor control. Figure 5 lists different clinical iCCA scenarios and recommended locoregional treatments.

Position in clinical guidelines

TA has been used increasingly as a definitive treatment for small iCCA tumors ≤3 cm.[66] The National Comprehensive Cancer Network (NCCN) guidelines recognize TA as a potential curative option for this select group of patients.[67] If SR or TA is not feasible, TACE or TARE may be offered either as a standalone treatment or in combination with systemic chemotherapy.[67]

Oligometastatic disease

Locoregional treatments, including both image-guided ablation and transarterial approaches, have achieved notable effectiveness in managing limited metastatic lesions. These approaches are used increasingly and are incorporated into treatment algorithms for multiple malignancies, including colorectal carcinoma, RCC, and soft tissue sarcomas.

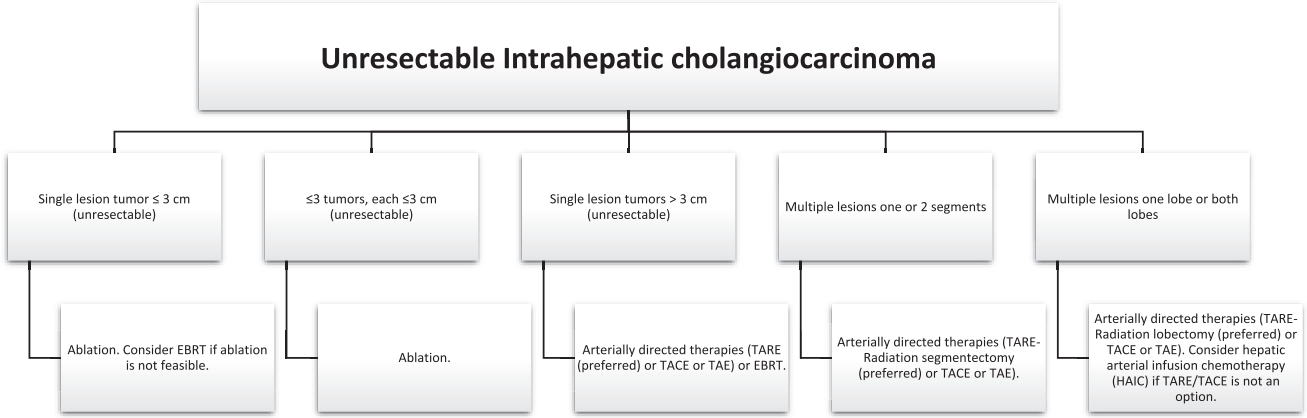

FIGURE 5 Illustration of recommended locoregional therapies (with or without systemic therapy) for unresectable intrahepatic cholangiocarcinoma. EBRT indicates external-beam radiation therapy; TAE, transarterial bland embolization; TACE, transarterial chemoembolization; TARE, transarterial radioembolization.

Metastatic colorectal cancer

Hepatic metastases

The liver is the most common site of colorectal cancer metastases, whereas colorectal cancer is the most common malignancy to metastasize to the liver.[76] CLMs occur in approximately 20% of patients with colorectal cancer at the time of diagnosis and in up to 80% of such patients during the disease course.[77–79] Liver involvement is thought to be the most common cause of mortality among patients with colorectal cancer.[80]

For patients with oligometastatic colorectal disease, the 2025 NCCN guidelines endorse TA as an equivalent therapy to SR for CLMs measuring up to 3 cm in greatest dimension, provided that the location of disease allows ablation with adequate margins.[81,82] As treatment paradigms evolve, ablation is expected to play an increasingly significant role as a first-option therapy to replace surgery for selected patients with CLMs.[83]

TA is most effective for tumors up to 3 cm in size, for which treatment with TA is associated with low rates of local tumor progression.[84–88] Although 3 cm is a common upper threshold for ablation, tumors up to 5 cm may also be treated with ablation if their location allows for overlapping ablations to achieve sufficient margins.[88] Most centers perform ablation for patients who have up to five CLMs, and treatment of more than five tumors is reserved for carefully selected patients.[88]

Ablation can be combined with or performed after systemic therapies. Contemporary advances in systemic therapies for colorectal cancer have improved response rates, often reducing the size of CLMs until they are undetectable on imaging. However, up to 83% of disappearing liver metastases still harbored viable tumor cells upon surgical pathologic examination or follow-up imaging at 1 year,[89] although contemporary studies suggest that this may be lower.[90] Therefore, subsequent ablation or SR is required to ensure complete treatment of CLMs.[91,92]

A noninferiority phase 3 trial compared the outcomes of patients with CLMs ≤3 cm who were randomized to receive either TA or surgery.[83] There was no significant difference in OS (p = .83) between the two groups, although the TA group demonstrated reduced complications, reduced mortality, shorter hospital stays, and improved local control in a per-tumor analysis.[83]

Studies have demonstrated that the independent predictors for postablation local tumor control are a tumor size ≤3 cm and an ablative margin ≥5 mm. For example, one study reported an improved median OS for ablated tumors ≤3 cm compared with tumors >3 cm (41 vs. 25 months; p = .005). In addition, CLM ablations with margins ≥5 mm have exhibited significantly lower recurrence rates than those with margins <5 mm.[93,94] Software-based margin quantification can provide three-dimensional margin assessment during the procedure to ensure that the intended margins have been achieved.[49] Figure 6 shows images from one such patient who had a solitary CLM treated with MWA.

In patients with hepatic CLM who are not candidates for either SR or ablative therapies, TARE is an option. Ideal candidates for TARE have a hepatic tumor burden that is <25% of the total liver volume, with no to minimal extrahepatic disease. A potential TARE candidate should have a life expectancy of at least 3 months and bilirubin levels <2.0 mg/dL with a good performance status (Eastern Cooperative Oncology Group performance status ≤2). At our institution, for patients with advanced disease, if there are systemic options, we prefer starting systemic therapy to achieve disease control before radioembolization.

Several prospective studies using TARE for the first-line and second-line treatment of CLMs have been completed.[95,96] In the FOXFIRE/SIRFLOX studies (ClinicalTrials.gov identifiers NCT00724503 and NCT01721954, respectively), the addition of TARE (SIR-Spheres; Sirtex) to FOLFOX (folinic acid, fluorouracil, and oxaliplatin) in the first-line setting was not associated with an improvement in OS or PFS; however, an important limitation of that study was the lack of advanced dosimetry for treatment planning.[95] In

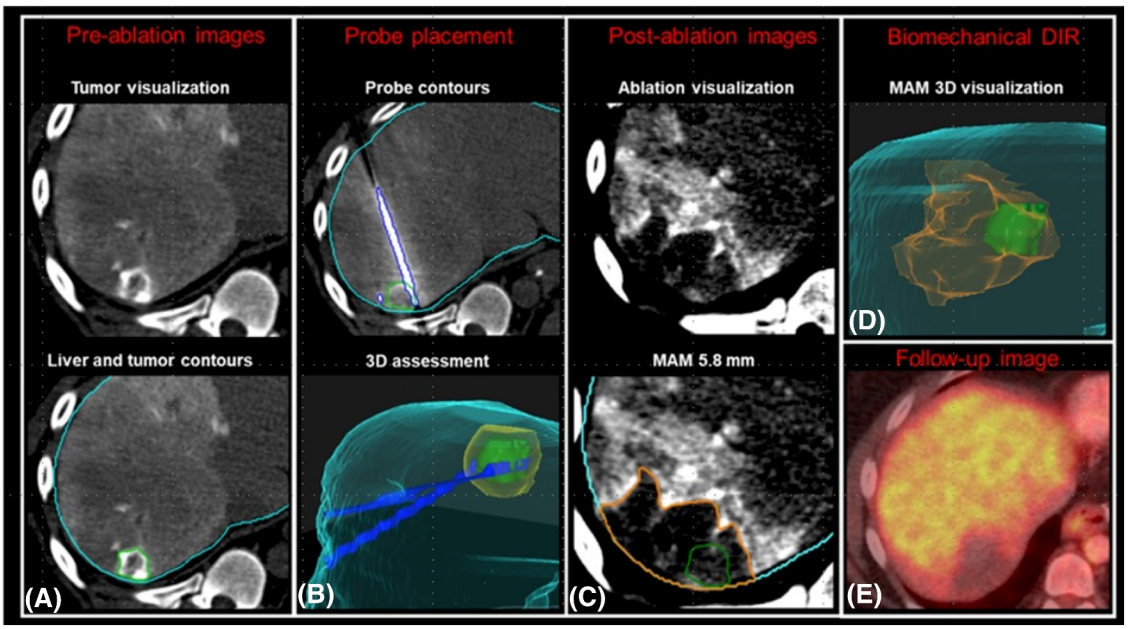

FIGURE 6 A patient aged 45 years with a solitary CRC liver metastasis. (A) An intraprocedural preablation CT during hepatic arteriography imaging with artificial intelligence-based autosegmentation of the liver (blue) and the tumor (green) revealed a 2.0-cm CLM on segment 7. (B) *Top:* Microwave applicators (blue) within the target tumor shown on a noncontrast CT image. *Bottom:* A 3D reconstruction of the CT images showed the microwave applicators (blue) within the tumor (green) with the preplanned, expanded ablation coverage of 5 mm (yellow). (C) *Top:* Intraprocedural postablation showed the ablation zone; the tumor was no longer visualized because it was encompassed by the ablation zone. *Bottom:* Artificial intelligence-based segmentation was used to visualize the ablation zone and tumor; the tumor was projected from the preablation image by image co-registration using biomechanical deformable registration. (D) A 3D representation showed the ablation zone covering the entire tumor with the intended minimal ablative margin (6.4 mm). (E) A fused positron emission tomography–CT image showed that the tumor had a complete response to the ablation at 2 months. 3D indicates three-dimensional; CLM, colorectal liver metastasis; CRC, colorectal carcinoma; CT, computed tomography; DIR, deformable image registration; MAM, minimum ablative margin.

the EPOCH study (ClinicalTrials.gov identifier NCT01483027), patients with CLMs whose disease progressed on first-line therapy were randomized to receive second-line therapy with or without TARE (TheraSpheres; Boston Scientific). Patients who received TARE had statistically significant longer PFS (8.0 vs. 7.2 months; $p = .0013$) and hepatic PFS (9.1 vs. 7.2 months; $p < .001$)—both primary end points—than those who did not receive TARE; however, OS did not differ significantly between groups. Again, the lack of advanced dosimetry for treatment planning was a key limitation of that study.[96]

Although TARE for CLMs in the third-line and later settings has not shown efficacy in clinical trials, in our clinical practice, we use TARE to treat select patients who have colorectal cancer in third-line and later settings with palliative intent.[97,98] Even in this case, all patients undergo treatment planning with advanced dosimetry given its benefits over the prior dosimetry methods, because studies have demonstrated a clinical benefit in patients who receive a tumor dose above a certain threshold.[99]

Colorectal pulmonary metastasis

Similar to the recommendations for hepatic colorectal metastases, NCCN guidelines support the use of ablation for pulmonary metastases in patients who are not surgical candidates or in selected surgical candidates who have small tumors that can be completely ablated with adequate margins. Percutaneous TA is primarily used as a definitive treatment in patients with oligometastatic pulmonary disease (lesions <3 cm).[100] For patients in whom complete tumor control is not possible (e.g., patients with greater than 5 lesions and patients with multiorgan or mediastinal lymphadenopathy), ablation may be used for specific tumors that are growing disproportionately to others despite systemic therapy with the objective of improving quality of life.[101] Although few quality-of-life studies exist for lung ablation, existing studies support its potential use for a chemotherapy holiday of up to approximately 10–20 months and some subjective improvement in quality of life.[102,103]

OS after TA of lung metastases varies based on patient selection factors, such as tumor type, tumor characteristics, the size and number of lesions, but is similar to the OS achieved with SR. This inherent heterogeneity is particularly evident in colorectal metastases, in which 5-year survival rates have ranged from approximately 30% to 70%.[102,104,105] These variations are attributed to differences in study populations: some studies focused on patients who had one or two small lesions, whereas others included those who had poor performance status or extensive bilateral or multilobar disease. Similar discrepancies have been observed in surgical and radiation studies, which nonetheless reported similar outcomes.[106–108]

One prospective study investigated at the results from RFA in 1037 lung metastases, of which 52% were colorectal in origin. RFA resulted in a median OS of 5.1 years, with 1-year and 5-year survival rates of 92.4%, and 51.5%, respectively.[109] In another perspective, multicenter study with 5-year follow-up involving 50 patients and 60 pulmonary lesions (42.5% colorectal in origin), the overall local tumor control rate was 87.9% and 79.2% at 3 and 5 years, respectively. The 3-year and 5-year DFS rates were 74.8% and 55.3%, respectively, and the respective 3-year and 5-year OS rates were 62.3% and 46.7%.[110] These outcomes align with those from surgical data, including a multicenter surgical registry study that reported a 5-year OS rate of 53.5%[109,111] and a meta-analysis of 2925 colorectal pulmonary metastases that indicated OS rates between 27% and 68% at 5 years.[112] However, to our knowledge, there are no randomized trials to prospectively inform their comparative efficacy. Figure 7 lists different clinical metastatic colorectal carcinoma scenarios and recommended locoregional treatments.

Metastatic renal cell carcinoma

The NCCN guidelines endorse ablative therapy in patients with oligometastatic disease secondary to RCC who are not eligible for metastectomy. Bang et al.[113] investigated the feasibility of TA for local tumor control in oligometastatic RCC, targeting 72 tumors across various anatomic sites, including the lung, liver, and soft tissues, in 27 patients. The median OS was 2.7 years. Only two tumors showed postablation recurrence.[113] Similarly, Welch et al. assessed the safety and oncologic efficacy of TA in managing 82 metastatic RCC lesions in 61 patients involving a range of organ systems. Local tumor control was achieved in 87.5% of all lesions. The local RFS rates was 94% at 1 year and declined to 83% at 3 years. The corresponding OS rates were 87% and 76% at 1 and 3 years, respectively.[114]

Renal cell carcinoma osseous metastasis

Bone is a common site of metastasis for advanced RCC. Although most data on TA have been obtained in the palliative setting for pain control, ablation has also been used to achieve local control of oligometastatic disease.

Gardner et al. reported the outcomes of using TA to achieve local control for RCC with metastatic bone lesions.[115] Their retrospective study included 40 patients with 50 lesions. Of the 40 patients, 25 (63%) had oligometastatic disease, defined as 5 or fewer metastases at the time of ablation. With a median follow-up of 35 months (range, 22.7–74.4 months), the overall local tumor control rate was 82% (41 of 50 lesions), with a significantly higher local tumor control rate noted in patients who had oligometastatic disease compared with those who had greater than five metastases (96% vs. 53%, respectively; $p = .001$).

Renal cell carcinoma pulmonary metastasis

In a cohort study conducted by Soga et al.[116] involving 39 patients with pulmonary metastases secondary to RCC who underwent TA, the 1-year OS rate was 90% and declined to 52% at both 3 years and 5 years. These findings were further supported by Gonnet et al.,[117] who evaluated 53 patients undergoing TA for 100 lung metastases and reported a 91% local tumor control rate and 1-year and 5-year OS rates of 94% and 62%, respectively.

In another study by de Baere et al.,[109] 68 of 566 patients underwent TA for lung metastases from RCC. The authors reported 5-year OS and PFS rates of 53.8% and 9.2%, respectively. Notably, these OS outcomes are comparable to those reported in the surgical literature, in which 5-year OS rates after pulmonary metastasectomy for metastatic RCC range from 36% to 45%.[118,119] Figure 8 lists different clinical metastatic RCC scenarios and recommended locoregional treatment.

Metastatic soft tissue sarcoma

Soft tissue sarcomas comprise a group of rare malignancies that often arise in young adults and adolescents. Although surgery is the mainstay of treatment, the role of local ablative treatment in such patients is expanding. Considering the expanding role of local IO

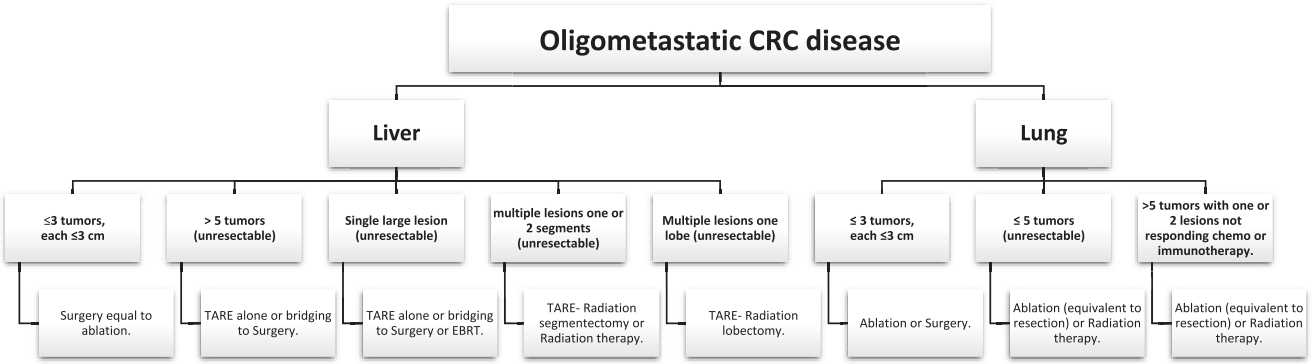

FIGURE 7 Illustration of the recommended locoregional therapies (with or without systemic therapy) for oligometastatic colorectal cancer. CRC indicates colorectal cancer; EBRT, external-beam radiation therapy; TARE, transarterial radioembolization.

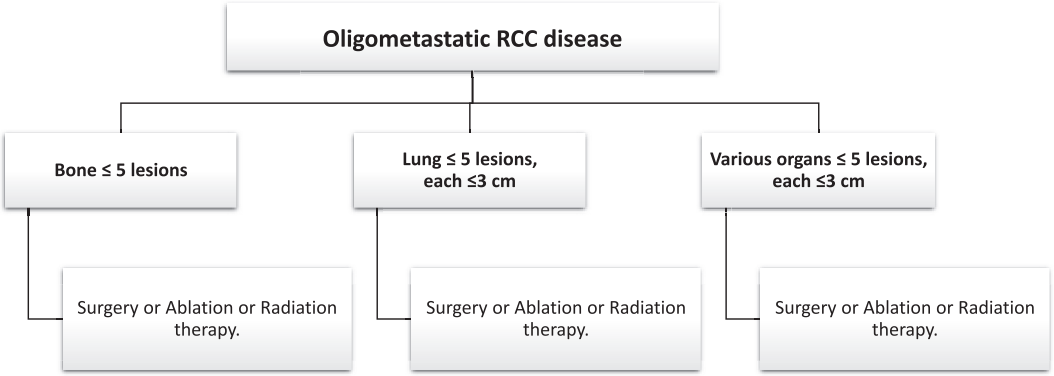

FIGURE 8 Illustration of recommended locoregional therapies (with or without systemic therapy) for oligometastatic renal cell carcinoma. RCC indicates renal cell carcinoma.

therapies, the NCCN guidelines have incorporated IO-based local therapies into various treatment algorithms for patients with sarcoma.[103,109,120–131]

Outcomes

Many recent studies have supported IO applications for soft tissue sarcomas.[103,109,121,123–125] In a retrospective, multicenter study by the French Sarcoma Group,[121] Falk et al. assessed the impact of local ablative treatment on the survival of patients with oligometastatic sarcoma, defined as the presence of between one and five concurrent metastatic lesions, irrespective of their anatomic locations or histologic subtypes. After matching patient cohorts based on baseline characteristics, those investigators compared the survival outcomes of patients who had oligometastatic sarcoma disease and received local treatment ($n = 164$) with the outcomes of those who did not receive local treatment ($n = 117$). Local ablative treatment appeared to improve OS in patients with oligometastatic sarcoma (2-year OS, 63% vs. 36.3%; $p < .0001$).[121]

We reported our experience with 217 percutaneous CA procedures for 250 recurrent or metastatic soft tissue sarcoma lesions in 141 patients. The median follow-up was 25 months (range, 3–80 months). The 1-year and 2-year local PFS rates were 86% and 80%, respectively, whereas the respective OS rates were 89% and 80%.[124] Figure 9 provides images of a leiomyosarcoma metastasis to the right gluteal musculature that were treated with CA for local control.

Hepatic metastasis

Although available data for sarcomas are limited, hepatic ablation has been shown to be an effective and safe treatment option in properly selected patients.[123,132–135] In a retrospective study, Awad et al. evaluated the outcomes of percutaneous TA of soft tissue sarcoma liver metastases, including 84 liver metastases in 55 patients.[123] In their study, complications developed in two patients (3.6%), including infection/abscess formation and pneumothorax. The local tumor PFS rate was 80% at 3 years, and the OS was 86% at 3 years.[123] In addition, Hakime et al. evaluated the role of RFA as adjuvant therapy for metastatic gastrointestinal stromal tumors after tyrosine kinase inhibitor therapy.[133] That study included 17 patients with 27 metastatic liver lesions who underwent RFA after receiving a tyrosine kinase inhibitor. The local control rate was 100%, and no local recurrences occurred over a mean follow-up of 49 months.[133]

Pulmonary metastasis

Koelblinger et al. assessed outcomes after RFA of 55 lung metastatic lesions in 21 patients[136] and reported OS rates of 94% and 85% at 2 and 3 years, respectively, with a mean OS of 51 months. Similarly, de Baere et al. assessed RFA for pulmonary metastases in 51 patients with sarcoma and reported a 5-year OS rate of 41.5%[109] and a PFS rate of 15.9% at 5 years.[109] Palussiere et al. also reported their experience using RFA for pulmonary metastases from sarcoma in 29 patients and observed OS rates of 92.2% and 65.2% at 1 and 3 years, respectively.[137] Sato et al. assessed 46 patients with sarcoma grom 144 lung metastases treated with RFA and reported primary local tumor control rates of 83.5% at 1 year and 76.3% at 2 years and secondary local tumor control rates (after a second ablation) of 90.0% at 1 year and 81.4% at 2 years. The OS rates were 80.6%, 70.1%, and 47.1% at 1, 2, and 3 years, respectively.[138] Figure 10 provides images of a pulmonary metastatic lesion from sarcoma that was treated with TA.

Position in clinical guidelines

Ablative therapy is an option for patients with soft tissue sarcomas who are not eligible for SR because of comorbidities and those with local recurrent disease, oligometastatic disease, or disease progression despite conventional therapy, although its use in patients who had disease stability after systemic treatment is also offered.[103,109,120–125] TA has been shown to play a curative role and improve survival in patients with oligometastatic disease.[121] In addition, TA can treat multiple lesions in a single session and reduce morbidity compared with repeated SR.[109,121,122] However, for patients who have disseminated

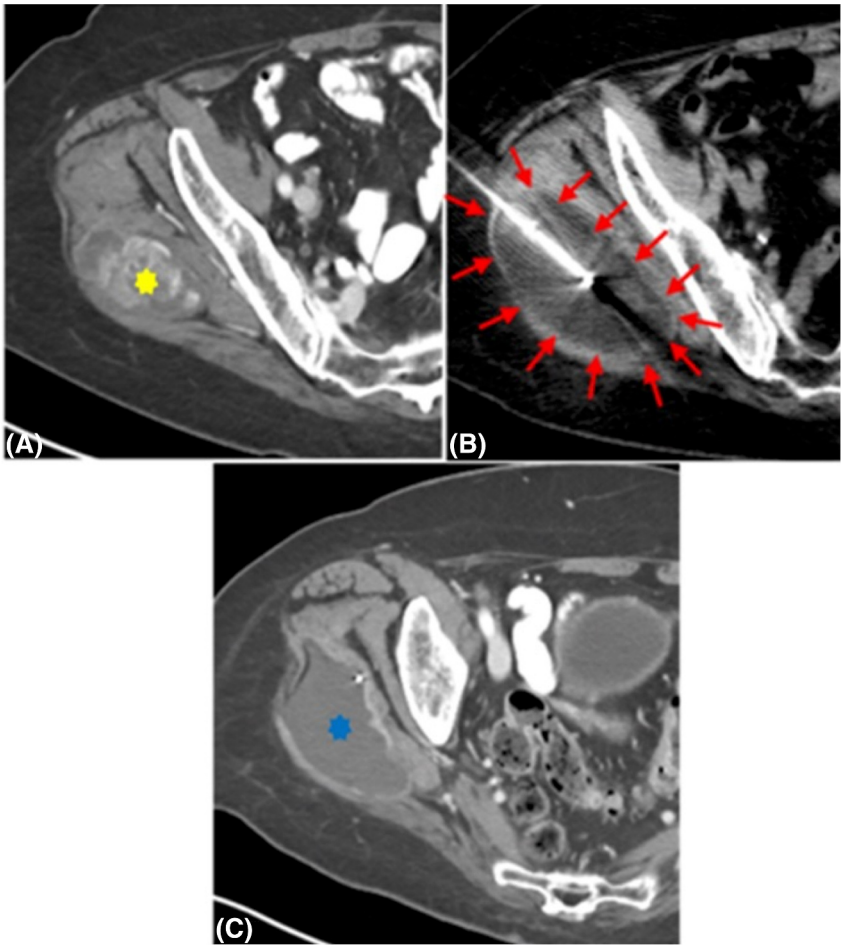

FIGURE 9 A woman aged 71 years with leiomyosarcoma metastasis to the right gluteal musculature. (A) Contrast-enhanced computed tomography showing a soft tissue mass (red asterisk) in the right gluteal musculature consistent with leiomyosarcoma metastasis. (B) The metastatic lesion was treated with percutaneous cryoablation (red arrows) under computed tomography image guidance. To prevent injury to the adjacent sciatic nerve, continuous electromyography and somatosensory evoked-potential monitoring was performed throughout the procedure. (C) Follow-up imaging at 3 months demonstrated successful local control of this lesion, with extensive necrosis (blue asterisk) throughout the tumor.

metastatic disease, TA can be combined safely with immunotherapy[126] or chemotherapy[125] as a means to provide a break from systemic treatment[103,125] or for palliation.[122] Furthermore, for patients who have liver-dominant metastatic disease who are not candidates for surgery, catheter-directed transarterial therapy (TAE, TACE, TARE) has shown evidence of efficacy.[127–131] Figure 11 lists different clinical metastatic sarcoma scenarios and recommended locoregional treatments.

Bone metastases from solid tumors

Bone is the third most common site for metastasis. Approximately 50% of patients with osseous metastatic disease experience refractory bone pain, with subsequent functional impairment and diminished quality of life.[139–141] TA affords an option for definitive treatment and also plays a role in the palliation of symptoms associated with bone metastases, including pain.[142–149]

Outcomes

TA has been shown to achieve local control in patients with oligometastatic disease.[150–152] In a retrospective study, Erie et al.[152] evaluated the efficacy and safety of percutaneous TA (16 CAs, two RFAs) for the treatment of prostate cancer with oligometastatic disease, most of which were bone metastases. Over a median follow-up of 27 months (range, 5–56 months), local tumor control was achieved in 15 of 18 metastases (83%), and local recurrence was identified in three metastases (17%), with a median time to recurrence of 3.5 months (range, 3–38 months). The 24-month PFS rate was 43%. For seven patients with androgen-deprivation therapy–naive disease, all metastatic lesions were successfully ablated, and local tumor control was achieved in 100% of lesions. No major complications were reported.[152]

Wallace et al.[153] conducted a retrospective analysis of 55 patients who had spinal osseous metastases treated with RFA in conjunction with vertebral augmentation. At the 3-month follow-up, local tumor control on imaging was achieved in 89% of patients. The

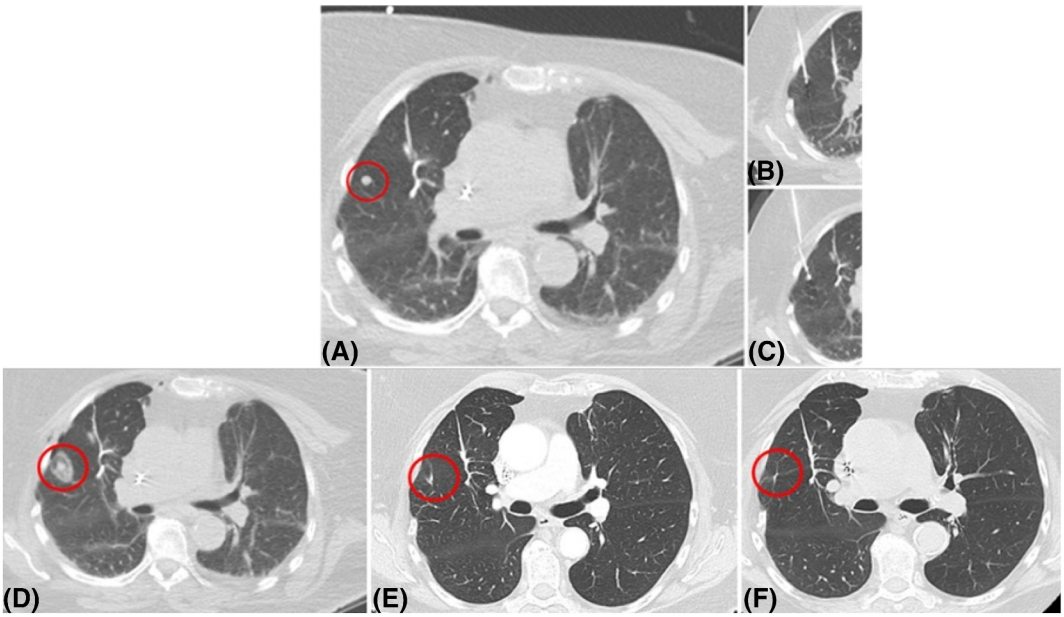

FIGURE 10 A woman aged 73 years with oligometastatic uterine sarcoma involving the lung. (A) Follow-up CT scans of a 7-mm lesion (red circle) in the right upper lung showed a progressive increase in size. (B,C) Cryoablation was performed using two probes surrounding the lesion. (D) An immediate postprocedure CT image demonstrated an adequate ablation zone encompassing the nodule with an adequate safety margin. (E,F) Follow-up CT scans at (E) 1 year and (F) 8 years after cryoablation revealed postablation changes with no signs of recurrent disease. CT indicates computed tomography.

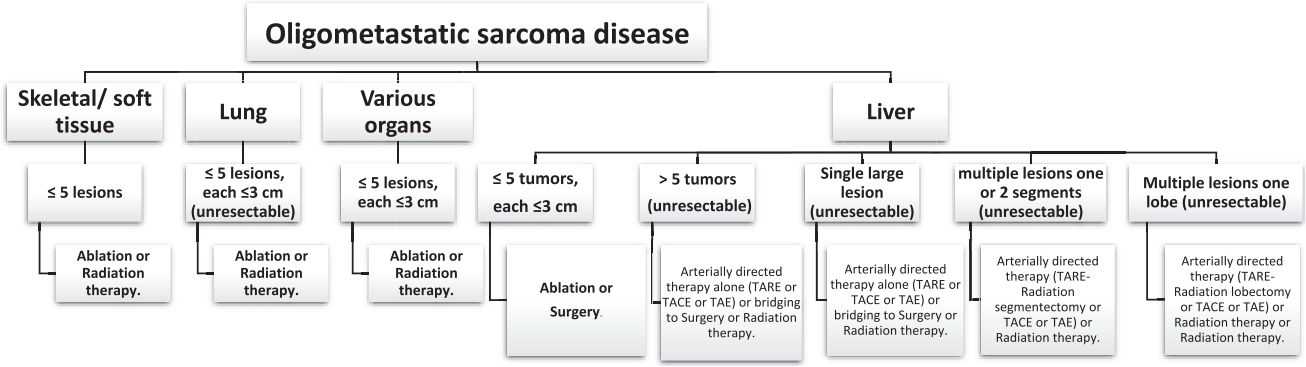

FIGURE 11 Illustration of recommended locoregional therapies (with or without systemic therapy) for oligometastatic sarcoma. TAE indicates transarterial bland embolization; TACE, transarterial chemoembolization; TARE, transarterial radioembolization.

12-month tumor control rate was 70%. Among patients with ongoing systemic metastatic progression, the local tumor control rate at 12 months was 67% (18 of 27 patients).

RFA was the first TA modality used to treat painful bone metastases. A foundational study by Goetz et al. described 43 patients at multiple institutions who received RFA for painful osteolytic bone metastases.[145] These patients had exhausted conventional treatments for these lesions, with 74% of patients having received prior radiation therapy. Clinically significant pain relief was observed in 95% of patients, and TA was associated with a decrease in narcotic pain medication use. These results motivated a multicenter American College of Radiology Imaging Network clinical trial evaluating TA for pain palliation from solitary painful bone metastases.[154] In that study, 49 patients with solitary bone metastases up to 8 cm in greatest dimension were treated with RFA, and postprocedure pain scores and imaging findings were analyzed. Ablation of the bone–tumor interface was identified as a significant factor in improved pain response after ablation; however, the ablated tumor volume was not associated with better pain relief.[154] Given these results, TA in this setting remains highly clinically meaningful even if complete coverage of the target lesion is not possible.

In the prospective, single-arm OPuS One study[148] of 206 patients who underwent spine RFA, the total adverse event rate was 2.9%, and none of these events included spinal cord or nerve thermal injury. Pain relief of at least 2 points on the Brief Pain Inventory scale was noted within 3 days of the intervention and lasted up to 12 months.[148]

Several early studies with small patient cohorts evaluated CA for painful bone metastases across a range of histologic types and

imaging guidance modalities.[155,156] The initial findings were further validated in multicenter studies; these studies also indicated that CA was associated with durable pain relief.[147,157] In the MOTION study,[157] a prospective multicenter trial of patients with metastatic bone disease, the authors observed that CA resulted in a mean decrease in pain scores of 2.6 points starting 1 week after the procedure and lasting for up to 6 months.[157]

TA can be combined with other therapies—such as radiation,[145–147] systemic treatment,[148,149] embolization,[158] or cementoplasty[142]—and its use is often determined on a case-by-case basis. Although prospective trials are lacking, retrospective studies and clinical experience support the safety and potential synergistic benefit of these multimodal approaches. Treatment decisions are typically individualized based on tumor location, patient symptoms, prior therapies, and overall disease burden to optimize outcomes and minimize complications. Figure 12 provides images of a metastatic RCC lesion to the left ischium and acetabulum that was treated using combined locoregional therapies.

In summary, percutaneous TA represents an effective local treatment strategy for achieving tumor control in patients with oligometastatic bone metastases. Moreover, TA has demonstrated encouraging outcomes in mitigating disease progression and improving survival, and it offers a reliable treatment for patients with painful skeletal lesions that can be used alone or in combination with other treatment modalities.

Position in clinical guidelines

The Cardiovascular and Interventional Radiological Society of Europe guidelines include TA as definitive treatment for secondary bone metastases in selected patients, including those

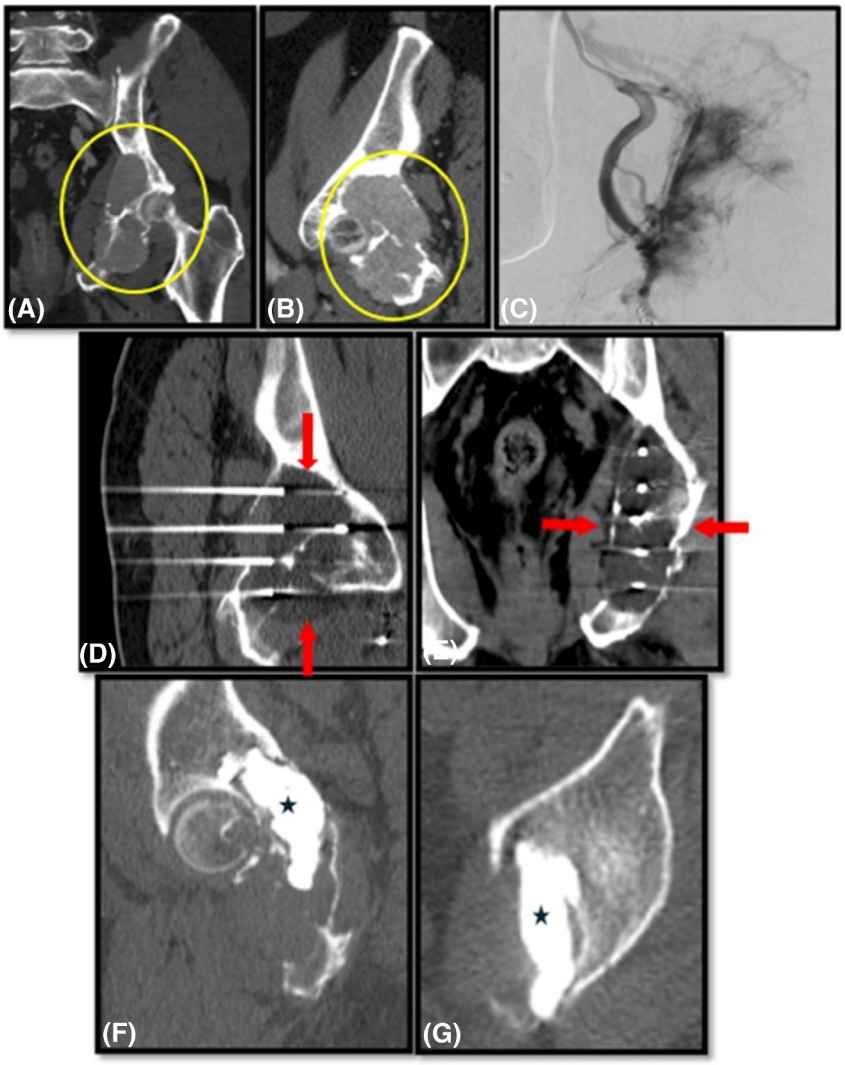

FIGURE 12 A man aged 58 years with clear cell renal cell carcinoma. (A,B) Metastatic lesion from RCC (red circle) extensively involved the left acetabulum and ischium. After a multidisciplinary discussion, the patient was referred to interventional radiology. (C–G) The patient was treated with a combination of minimally invasive therapies designed to eliminate the underlying tumor, including (C) transarterial embolization and (D,E) cryoablation (red arrows), and (F,G) to stabilize the weight-bearing components of the bone (cementoplasty; black stars). RCC indicates renal cell carcinoma.

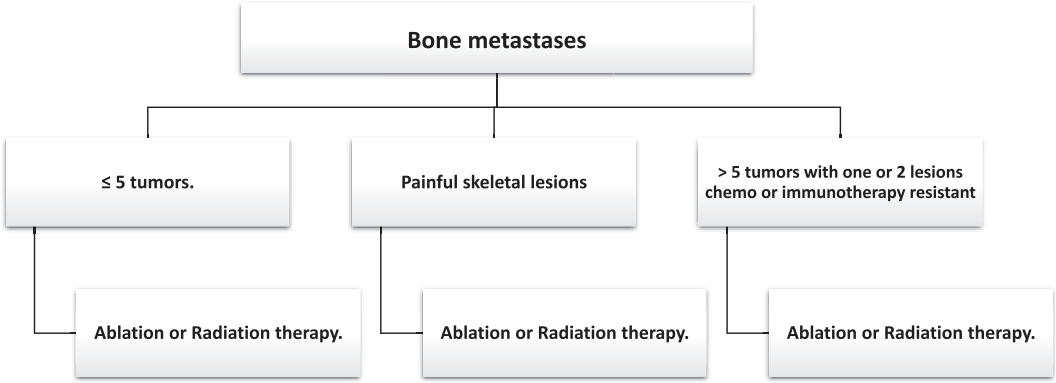

FIGURE 13 Illustration of recommended locoregional therapies (with or without systemic therapy) for bone metastases.

with oligometastatic disease (including oligorecurrent and oligo-progressive disease) who present with less than three to five potentially treatable metastases, each measuring <3 cm.[142] In addition, TA can be performed to prevent compromising adjacent critical structures that may occur secondary to tumor progression, particularly in spinal lesions.[142,143]

Furthermore, in accordance with recommendations of the NCCN and Cardiovascular and Interventional Radiological Society of Europe guidelines, image-guided ablation is a therapeutic option for patients who present with localized pain that is unresponsive to conventional therapies.[142,144] Such treatments can be provided as a single session and can lead to rapid and durable pain relief. TA (notably, RFA and CA) can also safely be combined with locoregional therapies, such as cement augmentation,[142] external-beam radiation,[145–147] and systemic therapies.[148,149] Figure 13 lists different clinical bone metastasis scenarios and recommended locoregional treatments.

CONCLUSION

In conclusion, percutaneous, minimally invasive, image-guided local therapies have been established as definitive treatment options for patients with early stage cancer or oligometastatic disease in different organs. These therapies, including ablation and embolization, offer precise tumor targeting while preserving surrounding healthy tissue, leading to favorable oncologic outcomes with minimal morbidity. Long-term clinical data have demonstrated that ablation and embolization are associated with durable local oncologic control and improved survival outcomes. Optimal patient selection guided by a multidisciplinary team approach remains critical to ensuring successful treatment. Future randomized controlled studies will further define the role of these minimally invasive therapies and solidify their place in the evolving landscape of oncologic treatment.

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CONFLICT OF INTEREST STATEMENT

Kamran Ahrar reports personal/consulting fees from Penumbra Inc. outside the submitted work. Rahul A. Sheth reports personal/consulting fees from Boston Scientific Corporation, Inari Medical Inc., Johnson & Johnson, Medtronic Inc., Replimune, TriSalus Life Sciences, and Varian Medical Systems Inc. outside the submitted work. Ketan Y. Shah reports personal/consulting fees from Johnson & Johnson and Siemens outside the submitted work. Bruno C. Odisio reports grants/contracts from Ethicon, NeuWave Medical Inc., and RaySearch Laboratories AB; personal/consulting fees from Siemens; and service as an expert witness for the American Society of Clinical Oncology outside the submitted work. Alda L. Tam reports personal/consulting fees from Cook Medical LLC and support for other professional activities from Boston Scientific Corporation and Johnson & Johnson outside the submitted work. Armeen Mahvash reports grants/contracts from Boston Scientific Corporation, Siemens Healthcare, Sirtex Medical Inc., and TriSalus; and personal/consulting fees from Sirtex Medical Inc. outside the submitted work. Peiman Habibollahi reports personal/consulting fees from Sirtex Medical Inc. and TriSalus outside the submitted work. The remaining authors disclosed no conflicts of interest.

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REFERENCES

1. Mashoufi R, Mashoufi R. Interventional radiology for disease management: a narrative review. *Cureus*. 2023;15(11):e48603. doi:10.7759/cureus.48603
2. O'Brien B, van der Putten W. Quantification of risk-benefit in interventional radiology. *Radiat Prot Dosimetry*. 2008;129(1-3):59-62. doi:10.1093/rpd/ncn040
3. Gangi A, Dietemann JL, Schultz A, Mortazavi R, Jeung MY, Roy C. Interventional radiologic procedures with CT guidance in cancer pain management. *Radiographics*. 1996;16(6):1289-1304; discussion 1304-1286. doi:10.1148/radiographics.16.6.8946536
4. Siegel RL, Kratzer TB, Giaquinto AN, Sung H, Jemal A. Cancer statistics, 2025. *CA Cancer J Clin*. 2025;75(1):10-45. doi:10.3322/caac.21871
5. Laguna MP, Algaba F, Cadeddu J, et al. Current patterns of presentation and treatment of renal masses: a Clinical Research Office of the Endourological Society prospective study. *J Endourol*. 2014;28(7):861-870. doi:10.1089/end.2013.0724
6. Pierorazio PM, Johnson MH, Patel HD, et al. Management of renal masses and localized renal cancer: systematic review and meta-analysis. *J Urol*. 2016;196(4):989-999. doi:10.1016/j.juro.2016.04.081
7. Finelli A, Ismaila N, Bro B, et al. Management of small renal masses: American Society of Clinical Oncology clinical practice guideline. *J Clin Oncol*. 2017;35(6):668-680. doi:10.1200/jco.2016.69.9645
8. Campbell SC, Clark PE, Chang SS, Karam JA, Souter L, Uzzo RG. Renal mass and localized renal cancer: evaluation, management, and follow-up: AUA guideline: part I. *J Urol*. 2021;206(2):199-208. doi:10.1097/ju.0000000000001911
9. Motzer RJ, Jonasch E, Agarwal N, et al. NCCN Guidelines® Insights: Kidney Cancer, Version 2.2024. *J Natl Compr Canc Netw*. 2024;22(1):4-16. doi:10.6004/jnccn.2024.0008
10. Abdelsalam ME, Sabir SH, Fellman B, et al. Overall survival after image guided thermal ablation of pathologically proven T1a RCC in cancer survivors [abstract]. *J Clin Oncol*. 2016;34(15 suppl):e16134. doi:10.1200/jco.2016.34.15_suppl.e16134
11. Campbell S, Uzzo RG, Allaf ME, et al. Renal mass and localized renal cancer: AUA guideline. *J Urol*. 2017;198(3):520-529. doi:10.1016/j.juro.2017.04.100
12. Gervais DA, McGovern FJ, Arellano RS, McDougal WS, Mueller PR. Renal cell carcinoma: clinical experience and technical success with radio-frequency ablation of 42 tumors. *Radiology*. 2003;226(2):417-424. doi:10.1148/radiol.2262012062
13. Iguchi T, Hiraki T, Tomita K, et al. Simultaneous biopsy and radiofrequency ablation of T1a renal cell carcinoma. *Diagn Interv Imaging*. 2016;97(11):1159-1164. doi:10.1016/j.diii.2016.05.001
14. Karam JA, Ahrar K, Matin SF. Ablation of kidney tumors. *Surg Oncol Clin N Am*. 2011;20(2):341-353. viii, doi:10.1016/j.soc.2010.11.004
15. Karam JA, Ahrar K, Vikram R, et al. Radiofrequency ablation of renal tumours with clinical, radiographical and pathological results. *BJU Int*. 2013;111(6):997-1005. doi:10.1111/j.1464-410x.2012.11608.x
16. Abdelsalam ME, Ahrar K. Ablation of small renal masses. *Tech Vasc Interv Radiol*. 2020;23(2):100674. doi:10.1016/j.tvir.2020.100674
17. Abdelsalam ME, Awad A, Baiomy A, et al. Outcomes of radiofrequency ablation for solitary t1a renal cell carcinoma: a 20-year tertiary cancer center experience. *Cancers (Basel)*. 2023;15(3):909. doi:10.3390/cancers15030909
18. Atwell TD, Farrell MA, Leibovich BC, et al. Percutaneous renal cryoablation: experience treating 115 tumors. *J Urol*. 2008;179(6):2136-2140; discussion 2140-2131. doi:10.1016/j.juro.2008.01.144
19. Atwell TD, Vlaminck JJ, Boorjian SA, et al. Percutaneous cryoablation of stage T1b renal cell carcinoma: technique considerations, safety, and local tumor control. *J Vasc Interv Radiol*. 2015;26(6):792-799. doi:10.1016/j.jvir.2015.02.010
20. Gunn AJ, Joe WB, Salei A, et al. Percutaneous cryoablation of stage T1b renal cell carcinoma: safety, technical results, and clinical outcomes. *Cardiovasc Intervent Radiol*. 2019;42(7):970-978. doi:10.1007/s00270-019-02226-5
21. Ma Y, Bedir S, Cadeddu JA, Gahan JC. Long-term outcomes in healthy adults after radiofrequency ablation of T1a renal tumours. *BJU Int*. 2014;113(1):51-55. doi:10.1111/bju.12366
22. Marshall HR, Shakeri S, Hosseiny M, et al. Long-term survival after percutaneous radiofrequency ablation of pathologically proven renal cell carcinoma in 100 patients. *J Vasc Interv Radiol*. 2020;31(1):15-24. doi:10.1016/j.jvir.2019.09.011
23. Psutka SP, Feldman AS, McDougal WS, McGovern FJ, Mueller P, Gervais DA. Long-term oncologic outcomes after radiofrequency ablation for T1 renal cell carcinoma. *Eur Urol*. 2013;63(3):486-492. doi:10.1016/j.eururo.2012.08.062
24. Breen DJ, King AJ, Patel N, Lockyer R, Hayes M. Image-guided cryoablation for sporadic renal cell carcinoma: three- and 5-year outcomes in 220 patients with biopsy-proven renal cell carcinoma. *Radiology*. 2018;289(2):554-561. doi:10.1148/radiol.2018180249
25. Georgiades CS, Rodriguez R. Efficacy and safety of percutaneous cryoablation for stage 1A/B renal cell carcinoma: results of a prospective, single-arm, 5-year study. *Cardiovasc Intervent Radiol*. 2014;37(6):1494-1499. doi:10.1007/s00270-013-0831-8
26. Wah TM, Irving HC, Gregory W, Cartledge J, Joyce AD, Selby PJ. Radiofrequency ablation (RFA) of renal cell carcinoma (RCC): experience in 200 tumours. *BJU Int*. 2014;113(3):416-428. doi:10.1111/bju.12349
27. Zhou M, Mills A, Noda C, Ramaswamy R, Akinwande O. SEER study of ablation versus partial nephrectomy in cT1A renal cell carcinoma. *Future Oncol*. 2018;14(17):1711-1719. doi:10.2217/fon-2017-0678
28. Xing M, Kokabi N, Zhang D, Ludwig JM, Kim HS. Comparative effectiveness of thermal ablation, surgical resection, and active surveillance for T1a renal cell carcinoma: a Surveillance, Epidemiology, and End Results (SEER)-Medicare–linked population study. *Radiology*. 2018;288(1):81-90. doi:10.1148/radiol.2018171407
29. Uhlig A, Hahn O, Strauss A, et al. Treatment for localized T1a clear cell renal cell carcinoma: survival benefit for cryosurgery and thermal ablation compared to deferred therapy. *Cardiovasc Intervent Radiol*. 2018;41(2):277-283. doi:10.1007/s00270-017-1816-9
30. Larcher A, Trudeau V, Sun M, et al. Population-based assessment of cancer-specific mortality after local tumour ablation or observation for kidney cancer: a competing risks analysis. *BJU Int*. 2016;118(4):541-546. doi:10.1111/bju.13326
31. Talenfeld AD, Gennarelli RL, Elkin EB, et al. Percutaneous ablation versus partial and radical nephrectomy for T1a renal cancer: a population-based analysis. *Ann Intern Med*. 2018;169(2):69-77. doi:10.7326/m17-0585
32. Katsanos K, Mailli L, Krokidis M, McGrath A, Sabharwal T, Adam A. Systematic review and meta-analysis of thermal ablation versus surgical nephrectomy for small renal tumours. *Cardiovasc Intervent Radiol*. 2014;37(2):427-437. doi:10.1007/s00270-014-0846-9
33. Foltz G. Image-guided percutaneous ablation of hepatic malignancies. *Semin Intervent Radiol*. 2014;31(2):180-186. doi:10.1055/s-0034-1373792
34. Forner A, Llovet JM, Bruix J. Hepatocellular carcinoma. *Lancet*. 2012;379(9822):1245-1255. doi:10.1016/s0140-6736(11)61347-0
35. Yang B, Xi X, Yu H, et al. Evaluation of the effectiveness of surgical resection and ablation for the treatment of early-stage hepatocellular carcinoma: a retrospective cohort study. *Cancer Rep (Hoboken)*. 2024;7(3):e2030. doi:10.1002/cnr2.2030

36. Reig M, Forner A, Rimola J, et al. BCLC strategy for prognosis prediction and treatment recommendation: the 2022 update. *J Hepatol*. 2022;76(3):681-693. doi:10.1016/j.jhep.2021.11.018
37. Vogel A, Meyer T, Sapisochin G, Salem R, Saborowski A. Hepatocellular carcinoma. *Lancet*. 2022;400(10360):1345-1362. doi:10.1016/s0140-6736(22)01200-4
38. Wells SA, Hinshaw JL, Lubner MG, Ziemlewicz TJ, Brace CL, Lee FT Jr. Liver ablation: best practice. *Radiol Clin North Am*. 2015;53(5):933-971. doi:10.1016/j.rcl.2015.05.012
39. Lewandowski RJ, Kulik LM, Riaz A, et al. A comparative analysis of transarterial downstaging for hepatocellular carcinoma: chemoembolization versus radioembolization. *Am J Transplant*. 2009;9(8):1920-1928. doi:10.1111/j.1600-6143.2009.02695.x
40. Salem R, Johnson GE, Kim E, et al. Yttrium-90 radioembolization for the treatment of solitary, unresectable HCC: the LEGACY study. *Hepatology*. 2021;74(5):2342-2352. doi:10.1002/hep.31819
41. Chow PKH, Gandhi M, Tan SB, et al. SIRveNIB: selective internal radiation therapy versus sorafenib in Asia-Pacific patients with hepatocellular carcinoma. *J Clin Oncol*. 2018;36(19):1913-1921. doi:10.1200/jco.2017.76.0892
42. Vilgrain V, Pereira H, Assenat E, et al. Efficacy and safety of selective internal radiotherapy with yttrium-90 resin microspheres compared with sorafenib in locally advanced and inoperable hepatocellular carcinoma (SARAH): an open-label randomised controlled phase 3 trial. *Lancet Oncol*. 2017;18(12):1624-1636. doi:10.1016/s1470-2045(17)30683-6
43. Mansouri Z, Salimi Y, Hajianfar G, et al. The role of biomarkers and dosimetry parameters in overall and progression free survival prediction for patients treated with personalized (90)Y glass microspheres SIRT: a preliminary machine learning study. *Eur J Nucl Med Mol Imaging*. 2024;51(13):4111-4126. doi:10.1007/s00259-024-06805-8
44. Kolligs F, Arnold D, Golfieri R, et al. Factors impacting survival after transarterial radioembolization in patients with hepatocellular carcinoma: results from the prospective CIRT study. *JHEP Rep*. 2023;5(2):100633. doi:10.1016/j.jhepr.2022.100633
45. Llovet JM, Kelley RK, Villanueva A, et al. Hepatocellular carcinoma. *Nat Rev Dis Primers*. 2021;7(1):6. doi:10.1038/s41572-020-00240-3
46. Kawaguchi Y, Hasegawa K, Kashiwabara K, et al. Surgery versus ablation for hepatocellular carcinoma: a randomized controlled trial (SURF-RCT trial) and a nonrandomized prospective observational trial (SURF-Cohort trial). *J Clin Oncol*. 2025;43(23):2628-2638. doi:10.1200/jco-24-02030
47. Jia Z, Zhang H, Li N. Evaluation of clinical outcomes of radiofrequency ablation and surgical resection for hepatocellular carcinoma conforming to the Milan criteria: a systematic review and meta-analysis of recent randomized controlled trials. *J Gastroenterol Hepatol*. 2021;36(7):1769-1777. doi:10.1111/jgh.15440
48. Li FY, Li JG, Wu SS, et al. An optimal ablative margin of small single hepatocellular carcinoma treated with image-guided percutaneous thermal ablation and local recurrence prediction based on the ablative margin: a multicenter study. *J Hepatocell Carcinoma*. 2021;8:1375-1388. doi:10.2147/jhc.s330746
49. Odisio BC, Albuquerque J, Lin YM, et al. Software-based versus visual assessment of the minimal ablative margin in patients with liver tumours undergoing percutaneous thermal ablation (COVER-ALL): a randomised phase 2 trial. *Lancet Gastroenterol Hepatol*. 2025;10(5):442-451. doi:10.1016/s2468-1253(25)00024-x
50. Yang G, Xiong Y, Sun J, et al. The efficacy of microwave ablation versus liver resection in the treatment of hepatocellular carcinoma and liver metastases: a systematic review and meta-analysis. *Int J Surg*. 2020;77:85-93. doi:10.1016/j.ijsu.2020.03.006
51. Salem R, Gordon AC, Mouli S, et al. Y90 radioembolization significantly prolongs time to progression compared with chemoembolization in patients with hepatocellular carcinoma. *Gastroenterology*. 2016;151(6):1155-1163.e2. doi:10.1053/j.gastro.2016.08.029
52. Dhondt E, Lambert B, Hermie L, et al. (90)Y radioembolization versus drug-eluting bead chemoembolization for unresectable hepatocellular carcinoma: results from the TRACE phase II randomized controlled trial. *Radiology*. 2022;303(3):699-710. doi:10.1148/radiol.211806
53. Brown KT, Do RK, Gonen M, et al. Randomized trial of hepatic artery embolization for hepatocellular carcinoma using doxorubicin-eluting microspheres compared with embolization with microspheres alone. *J Clin Oncol*. 2016;34(17):2046-2053. doi:10.1200/jco.2015.64.0821
54. Kokabi N, Webster LA, Dabbous H, et al. Resin-based 90Y tumor dose as a predictor of duration of response and survival in patients with surgically unresectable hepatocellular carcinoma: a prospective single-arm study. *Clin Nucl Med*. 2024;49(9):799-805. doi:10.1097/rlu.0000000000005198
55. Mahvash A, Chartier S, Turco M, et al. A prospective, multicenter, open-label, single-arm clinical trial design to evaluate the safety and efficacy of (90)Y resin microspheres for the treatment of unresectable HCC: the DOORwaY90 (Duration Of Objective Response with arterial Ytrrium-90) study. *BMC Gastroenterol*. 2022;22(1):151. doi:10.1186/s12876-022-02204-1
56. Kokabi N, Camacho JC, Xing M, et al. Open-label prospective study of the safety and efficacy of glass-based yttrium 90 radioembolization for infiltrative hepatocellular carcinoma with portal vein thrombosis. *Cancer*. 2015;121(13):2164-2174. doi:10.1002/cncr.29275
57. Mazzaferro V, Sposito C, Bhoori S, et al. Yttrium-90 radioembolization for intermediate-advanced hepatocellular carcinoma: a phase 2 study. *Hepatology*. 2013;57(5):1826-1837. doi:10.1002/hep.26014
58. Memon K, Kulik L, Lewandowski RJ, et al. Radioembolization for hepatocellular carcinoma with portal vein thrombosis: impact of liver function on systemic treatment options at disease progression. *J Hepatol*. 2013;58(1):73-80. doi:10.1016/j.jhep.2012.09.003
59. Dawson LA, Winter KA, Knox JJ, et al. Stereotactic body radiotherapy vs sorafenib alone in hepatocellular carcinoma: the NRG Oncology/RTOG 1112 phase 3 randomized clinical trial. *JAMA Oncol*. 2025;11(2):136-144. doi:10.1001/jamaoncol.2024.5403
60. English K, Brodin NP, Shankar V, et al. Association of addition of ablative therapy following transarterial chemoembolization with survival rates in patients with hepatocellular carcinoma. *JAMA Netw Open*. 2020;3(11):e2023942. doi:10.1001/jamanetworkopen.2020.23942
61. European Association for the Study of the Liver. EASL clinical practice guidelines on the management of hepatocellular carcinoma. *J Hepatol*. 2025;82(2):315-374. doi:10.1016/j.jhep.2024.08.028
62. Garin E, Tselikas L, Guiu B, et al. Personalised versus standard dosimetry approach of selective internal radiation therapy in patients with locally advanced hepatocellular carcinoma (DOSISPHERE-01): a randomised, multicentre, open-label phase 2 trial. *Lancet Gastroenterol Hepatol*. 2021;6(1):17-29. doi:10.1016/s2468-1253(20)30290-9
63. Banales JM, Cardinale V, Carpino G, et al. Expert consensus document: cholangiocarcinoma: current knowledge and future perspectives, consensus statement from the European Network for the Study of Cholangiocarcinoma (ENS-CCA). *Nat Rev Gastroenterol Hepatol*. 2016;13(5):261-280. doi:10.1038/nrgastro.2016.51
64. Ilyas SI, Khan SA, Hallemeier CL, Kelley RK, Gores GJ. Cholangiocarcinoma—evolving concepts and therapeutic strategies. *Nat Rev Clin Oncol*. 2018;15(2):95-111. doi:10.1038/nrclinonc.2017.157
65. Nakeeb A, Pitt HA, Sohn TA, et al. Cholangiocarcinoma. A spectrum of intrahepatic, perihilar, and distal tumors. *Ann Surg*. 1996;224(4):

463-473; discussion 473-465. doi:10.1097/00000658-199610000-00005
66. Koay EJ, Odisio BC, Javle M, Vauthey JN, Crane CH. Management of unresectable intrahepatic cholangiocarcinoma: how do we decide among the various liver-directed treatments? *Hepatobiliary Surg Nutr*. 2017;6(2):105-116. doi:10.21037/hbsn.2017.01.16
67. Benson AB, D'Angelica MI, Abrams T, et al. *NCCN Guidelines® Insights: Biliary Tract Cancers, Version 1.2025*. National Comprehensive Cancer Network; 2025.
68. Pang C, Li J, Dou J, et al. Microwave ablation versus liver resection for primary intrahepatic cholangiocarcinoma within Milan criteria: a long-term multicenter cohort study. *eClinicalMedicine*. 2024;67:102336. doi:10.1016/j.eclinm.2023.102336
69. Edeline J, Lamarca A, McNamara MG, et al. Locoregional therapies in patients with intrahepatic cholangiocarcinoma: a systematic review and pooled analysis. *Cancer Treat Rev*. 2021;99:102258. doi:10.1016/j.ctrv.2021.102258
70. Zhang K, Yu J, Yu X, et al. Clinical and survival outcomes of percutaneous microwave ablation for intrahepatic cholangiocarcinoma. *Int J Hyperthermia*. 2018;34(3):292-297. doi:10.1080/02656736.2017.1327678
71. Charalampopoulos G, Iezzi R, Tsitskari M, et al. Role of percutaneous ablation in the management of intrahepatic cholangiocarcinoma. *Medicina (Kaunas)*. 2023;59(7):1186. doi:10.3390/medicina59071186
72. Li H, Chen L, Zhu GY, Yao X, Dong R, Guo JH. Interventional treatment for cholangiocarcinoma. *Front Oncol*. 2021;11:671327. doi:10.3389/fonc.2021.671327
73. Edeline J, Touchefeu Y, Guiu B, et al. Radioembolization plus chemotherapy for first-line treatment of locally advanced intrahepatic cholangiocarcinoma: a phase 2 clinical trial. *JAMA Oncol*. 2020;6(1):51-59. doi:10.1001/jamaoncol.2019.3702
74. Cheng B, Villalobos A, Sethi I, et al. Determination of tumor dose response thresholds in patients with chemorefractory intrahepatic cholangiocarcinoma treated with resin and glass-based Y90 radioembolization. *Cardiovasc Intervent Radiol*. 2021;44(8):1194-1203. doi:10.1007/s00270-021-02834-0
75. Levillain H, Duran Derijckere I, Ameye L, et al. Personalised radioembolization improves outcomes in refractory intra-hepatic cholangiocarcinoma: a multicenter study. *Eur J Nucl Med Mol Imaging*. 2019;46(11):2270-2279. doi:10.1007/s00259-019-04427-z
76. Nieuwenhuizen S, Puijk RS, van den Bemd B, et al. Resectability and ablatability criteria for the treatment of liver only colorectal metastases: multidisciplinary consensus document from the COLLISION Trial Group. *Cancers (Basel)*. 2020;12(7):1779. doi:10.3390/cancers12071779
77. Engstrand J, Nilsson H, Stromberg C, Jonas E, Freedman J. Colorectal cancer liver metastases—a population-based study on incidence, management and survival. *BMC Cancer*. 2018;18(1):78. doi:10.1186/s12885-017-3925-x
78. Manfredi S, Lepage C, Hatem C, Coatmeur O, Faivre J, Bouvier AM. Epidemiology and management of liver metastases from colorectal cancer. *Ann Surg*. 2006;244(2):254-259. doi:10.1097/01.sla.0000217629.94941.cf
79. Patel RK, Rahman S, Schwantes IR, et al. Updated management of colorectal cancer liver metastases: scientific advances driving modern therapeutic innovations. *Cell Mol Gastroenterol Hepatol*. 2023;16(6):881-894. doi:10.1016/j.jcmgh.2023.08.012
80. Lin YM, Paolucci I, Brock KK, Odisio BC. Image-guided ablation for colorectal liver metastasis: principles, current evidence, and the path forward. *Cancers (Basel)*. 2021;13(16):3926. doi:10.3390/cancers13163926
81. National Comprehensive Cancer Network (NCCN). *NCCN Guidelines® Insights: Colon Cancer, Version 2.2025*. NCCN; 2025. Accessed March 31, 2025. https://www.nccn.org/professionals/physician_gls/pdf/colon.pdf
82. National Comprehensive Cancer Network (NCCN). *NCCN Guidelines® Insights: Rectal Cancer, Version 2.2025*. NCCN; 2025. Accessed March 31, 2025. https://www.nccn.org/professionals/physician_gls/pdf/colon.pdf
83. van der Lei S, Puijk RS, Dijkstra M, et al. Thermal ablation versus surgical resection of small-size colorectal liver metastases (COLLISION): an international, randomised, controlled, phase 3 non-inferiority trial. *Lancet Oncol*. 2025;26(2):187-199. doi:10.1016/s1470-2045(24)00660-0
84. Hamada A, Yamakado K, Nakatsuka A, et al. Radiofrequency ablation for colorectal liver metastases: prognostic factors in non-surgical candidates. *Jpn J Radiol*. 2012;30(7):567-574. doi:10.1007/s11604-012-0089-0
85. Hammill CW, Billingsley KG, Cassera MA, Wolf RF, Ujiki MB, Hansen PD. Outcome after laparoscopic radiofrequency ablation of technically resectable colorectal liver metastases. *Ann Surg Oncol*. 2011;18(7):1947-1954. doi:10.1245/s10434-010-1535-9
86. Solbiati L, Ahmed M, Cova L, Ierace T, Brioschi M, Goldberg SN. Small liver colorectal metastases treated with percutaneous radiofrequency ablation: local response rate and long-term survival with up to 10-year follow-up. *Radiology*. 2012;265(3):958-968. doi:10.1148/radiol.12111851
87. Veltri A, Sacchetto P, Tosetti I, Pagano E, Fava C, Gandini G. Radiofrequency ablation of colorectal liver metastases: small size favorably predicts technique effectiveness and survival. *Cardiovasc Intervent Radiol*. 2008;31(5):948-956. doi:10.1007/s00270-008-9362-0
88. Gillams A, Goldberg N, Ahmed M, et al. Thermal ablation of colorectal liver metastases: a position paper by an international panel of ablation experts, the Interventional Oncology Sans Frontieres meeting 2013. *Eur Radiol*. 2015;25(12):3438-3454. doi:10.1007/s00330-015-3779-z
89. Benoist S, Brouquet A, Penna C, et al. Complete response of colorectal liver metastases after chemotherapy: does it mean cure? *J Clin Oncol*. 2006;24:3939-3945. doi:10.1200/jco.2006.05.8727
90. Kataoka K, Mauer M, Shiozawa M, et al. Diagnostic accuracy of imaging in assessing nonviability of disappearing colorectal liver metastasis. *JAMA Surg*. 2025;160(11):1212-1220. doi:10.1001/jamasurg.2025.3600
91. Newhook TE, Vauthey JN. Colorectal liver metastases: state-of-the-art management and surgical approaches. *Langenbecks Arch Surg*. 2022;407(5):1765-1778. doi:10.1007/s00423-022-02496-7
92. Passot G, Odisio BC, Zorzi D, et al. Eradication of missing liver metastases after fiducial placement. *J Gastrointest Surg*. 2016;20(6):1173-1178. doi:10.1007/s11605-016-3079-1
93. Shady W, Petre EN, Gonen M, et al. Percutaneous radiofrequency ablation of colorectal cancer liver metastases: factors affecting outcomes—a 10-year experience at a single center. *Radiology*. 2016;278(2):601-611. doi:10.1148/radiol.2015142489
94. Lin YM, Paolucci I, O'Connor CS, et al. Ablative margins of colorectal liver metastases using deformable CT image registration and autosegmentation. *Radiology*. 2023;307(2):e221373. doi:10.1148/radiol.221373
95. Wasan HS, Gibbs P, Sharma NK, et al. First-line selective internal radiotherapy plus chemotherapy versus chemotherapy alone in patients with liver metastases from colorectal cancer (FOXFIRE, SIRFLOX, and FOXFIRE-Global): a combined analysis of three multicentre, randomised, phase 3 trials. *Lancet Oncol*. 2017;18(9):1159-1171. doi:10.1016/s1470-2045(17)30457-6
96. Mulcahy MF, Mahvash A, Pracht M, et al. Radioembolization with chemotherapy for colorectal liver metastases: a randomized, open-label, international, multicenter, phase III trial. *J Clin Oncol*. 2021;39(35):3897-3907. doi:10.1200/jco.21.01839

97. Jeyarajah DR, Doyle MBM, Espat NJ, et al. Role of yttrium-90 selective internal radiation therapy in the treatment of liver-dominant metastatic colorectal cancer: an evidence-based expert consensus algorithm. *J Gastrointest Oncol*. 2020;11(2):443-460. doi:10.21037/jgo.2020.01.09
98. White J, Carolan-Rees G, Dale M, et al. Analysis of a national programme for selective internal radiation therapy for colorectal cancer liver metastases. *Clin Oncol (R Coll Radiol)*. 2019;31(1):58-66. doi:10.1016/j.clon.2018.09.002
99. Sankhla T, Cheng B, Nezami N, et al. Role of resin microsphere Y90 dosimetry in predicting objective tumor response, survival and treatment related toxicity in surgically unresectable colorectal liver metastasis: a retrospective single institution study. *Cancers (Basel)*. 2021;13(19):4908. doi:10.3390/cancers13194908
100. Genshaft SJ, Suh RD, Abtin F, et al. Society of Interventional Radiology multidisciplinary position statement on percutaneous ablation of non-small cell lung cancer and metastatic disease to the lungs: endorsed by the Canadian Association for Interventional Radiology, the Cardiovascular and Interventional Radiological Society of Europe, and the Society of Interventional Oncology. *J Vasc Interv Radiol*. 2021;32:1241.e1-1241.e12.
101. Cervantes A, Adam R, Rosello S, et al. Metastatic colorectal cancer: ESMO clinical practice guideline for diagnosis, treatment and follow-up. *Ann Oncol*. 2023;34(1):10-32. doi:10.1016/j.annonc.2022.10.003
102. Fonck M, Perez JT, Catena V, et al. Pulmonary thermal ablation enables long chemotherapy-free survival in metastatic colorectal cancer patients. *Cardiovasc Intervent Radiol*. 2018;41(11):1727-1734. doi:10.1007/s00270-018-1939-7
103. Sutton C, Zhang Y, Kim D, et al. Analysis of the chemotherapy-free interval following image-guided ablation in sarcoma patients. *Sarcoma*. 2020;2020:3852420-3852428. doi:10.1155/2020/3852420
104. Kurilova I, Gonzalez-Aguirre A, Beets-Tan RG, et al. Microwave ablation in the management of colorectal cancer pulmonary metastases. *Cardiovasc Intervent Radiol*. 2018;41(10):1530-1544. doi:10.1007/s00270-018-2000-6
105. Yan TD, King J, Sjarif A, et al. Treatment failure after percutaneous radiofrequency ablation for nonsurgical candidates with pulmonary metastases from colorectal carcinoma. *Ann Surg Oncol*. 2007;14(5):1718-1726. doi:10.1245/s10434-006-9271-x
106. Cao C, Wang D, Tian DH, Wilson-Smith A, Huang J, Rimner A. A systematic review and meta-analysis of stereotactic body radiation therapy for colorectal pulmonary metastases. *J Thorac Dis*. 2019;11(12):5187-5198. doi:10.21037/jtd.2019.12.12
107. Iida T, Nomori H, Shiba M, et al. Prognostic factors after pulmonary metastasectomy for colorectal cancer and rationale for determining surgical indications: a retrospective analysis. *Ann Surg*. 2013;257(6):1059-1064. doi:10.1097/sla.0b013e31826eda3b
108. Meimarakis G, Spelsberg F, Angele M, et al. Resection of pulmonary metastases from colon and rectal cancer: factors to predict survival differ regarding to the origin of the primary tumor. *Ann Surg Oncol*. 2014;21(8):2563-2572. doi:10.1245/s10434-014-3646-1
109. de Baere T, Auperin A, Deschamps F, et al. Radiofrequency ablation is a valid treatment option for lung metastases: experience in 566 patients with 1037 metastases. *Ann Oncol*. 2015;26(5):987-991. doi:10.1093/annonc/mdv037
110. Tinguely P, Ruiter SJS, Engstrand J, et al. A prospective multicentre trial on survival after Microwave Ablation VErsus Resection for Resectable Colorectal liver metastases (MAVERRIC). *Eur J Cancer*. 2023;187:65-76. doi:10.1016/j.ejca.2023.03.038
111. Casiraghi M, De Pas T, Maisonneuve P, et al. A 10-year single-center experience on 708 lung metastasectomies: the evidence of the "International Registry of Lung Metastases." *J Thorac Oncol*. 2011;6(8):1373-1378. doi:10.1097/jto.0b013e3182208e58
112. Gonzalez M, Poncet A, Combescure C, Robert J, Ris HB, Gervaz P. Risk factors for survival after lung metastasectomy in colorectal cancer patients: a systematic review and meta-analysis. *Ann Surg Oncol*. 2013;20(2):572-579. doi:10.1245/s10434-012-2726-3
113. Bang HJ, Littrup PJ, Goodrich DJ, et al. Percutaneous cryoablation of metastatic renal cell carcinoma for local tumor control: feasibility, outcomes, and estimated cost-effectiveness for palliation. *J Vasc Interv Radiol*. 2012;23(6):770-777. doi:10.1016/j.jvir.2012.03.002
114. Welch BT, Callstrom MR, Morris JM, et al. Feasibility and oncologic control after percutaneous image guided ablation of metastatic renal cell carcinoma. *J Urol*. 2014;192(2):357-363. doi:10.1016/j.juro.2014.03.006
115. Gardner CS, Ensor JE, Ahrar K, et al. Cryoablation of bone metastases from renal cell carcinoma for local tumor control. *J Bone Joint Surg Am*. 2017;99(22):1916-1926. doi:10.2106/jbjs.16.01182
116. Soga N, Yamakado K, Gohara H, et al. Percutaneous radiofrequency ablation for unresectable pulmonary metastases from renal cell carcinoma. *BJU Int*. 2009;104(6):790-794. doi:10.1111/j.1464-410x.2009.08459.x
117. Gonnet A, Salabert L, Roubaud G, et al. Renal cell carcinoma lung metastases treated by radiofrequency ablation integrated with systemic treatments: over 10 years of experience. *BMC Cancer*. 2019;19(1):1182. doi:10.1186/s12885-019-6345-2
118. Pfannschmidt J, Hoffmann H, Muley T, Krysa S, Trainer C, Dienemann H. Prognostic factors for survival after pulmonary resection of metastatic renal cell carcinoma. *Ann Thorac Surg*. 2002;74(5):1653-1657. doi:10.1016/s0003-4975(02)03803-1
119. Murthy SC, Kim K, Rice TW, et al. Can we predict long-term survival after pulmonary metastasectomy for renal cell carcinoma? *Ann Thorac Surg*. 2005;79(3):996-1003. doi:10.1016/j.athoracsur.2004.08.034
120. National Comprehensive Cancer Network (NCCN). *NCCN Guidelines®: Soft Tissue Sarcoma, Version 4.2024*. NCCN; 2024. Accessed November 21, 2024. https://www.nccn.org/professionals/physician_gls/pdf/sarcoma.pdf
121. Falk AT, Moureau-Zabotto L, Ouali M, et al. Effect on survival of local ablative treatment of metastases from sarcomas: a study of the French Sarcoma Group. *Clin Oncol*. 2015;27(1):48-55. doi:10.1016/j.clon.2014.09.010
122. de Baere T, Tselikas L, Gravel G, et al. Interventional radiology: role in the treatment of sarcomas. *Eur J Cancer*. 2018;94:148-155. doi:10.1016/j.ejca.2018.02.017
123. Awad A, Pal K, Yevich S, et al. Safety and efficacy of percutaneous image-guided ablation for soft tissue sarcoma metastases to the liver. *Cancer*. 2024;130(15):2703-2712. doi:10.1002/cncr.35330
124. Pal K, Awad A, Yevich S, et al. Safety and efficacy of percutaneous cryoablation for recurrent or metastatic soft-tissue sarcoma in adult patients. *AJR Am J Roentgenol*. 2024;223(4):e2431490. doi:10.2214/ajr.24.31490
125. Hirbe AC, Jennings J, Saad N, et al. A phase II study of tumor ablation in patients with metastatic sarcoma stable on chemotherapy. *Oncologist*. 2018;23(7):760-e76. doi:10.1634/theoncologist.2017-0536
126. Doshi A, Zhou M, Bui N, Wang DS, Ganjoo K, Hwang GL. Safety and feasibility of cryoablation during immunotherapy in patients with metastatic soft tissue sarcoma. *J Vasc Interv Radiol*. 2021;32(12):1688-1694. doi:10.1016/j.jvir.2021.08.017
127. Maluccio MA, Covey AM, Schubert J, et al. Treatment of metastatic sarcoma to the liver with bland embolization. *Cancer*. 2006;107(7):1617-1623. doi:10.1002/cncr.22191
128. Rajan DK, Soulen MC, Clark TW, et al. Sarcomas metastatic to the liver: response and survival after cisplatin, doxorubicin,

mitomycin-C, ethiodol, and polyvinyl alcohol chemoembolization. *J Vasc Interv Radiol*. 2001;12(2):187-193. doi:10.1016/s1051-0443(07)61824-7

129. Krzyston H, Morse B, Deperalta D, et al. Liver-directed treatments of liver-dominant metastatic leiomyosarcoma. *Diagn Interv Radiol*. 2020;26(5):449-455. doi:10.5152/dir.2020.19405
130. Miller MD, Sze DY, Padia SA, et al. Response and overall survival for yttrium-90 radioembolization of hepatic sarcoma: a multicenter retrospective study. *J Vasc Interv Radiol*. 2018;29(6):867-873. doi:10.1016/j.jvir.2018.01.775
131. Testa S, Bui NQ, Wang DS, Louie JD, Sze DY, Ganjoo KN. Efficacy and safety of trans-arterial yttrium-90 radioembolization in patients with unresectable liver-dominant metastatic or primary hepatic soft tissue sarcomas. *Cancers (Basel)*. 2022;14(2):324. doi:10.3390/cancers14020324
132. Glazer DI, Tatli S, Shyn PB, Vangel MG, Tuncali K, Silverman SG. Percutaneous image-guided cryoablation of hepatic tumors: single-center experience with intermediate to long-term outcomes. *AJR Am J Roentgenol*. 2017;209(6):1381-1389. doi:10.2214/ajr.16.17582
133. Hakime A, Le Cesne A, Deschamps F, et al. A role for adjuvant RFA in managing hepatic metastases from gastrointestinal stromal tumors (GIST) after treatment with targeted systemic therapy using kinase inhibitors. *Cardiovasc Intervent Radiol*. 2014;37(1):132-139. doi:10.1007/s00270-013-0615-1
134. Jones RL, McCall J, Adam A, et al. Radiofrequency ablation is a feasible therapeutic option in the multi modality management of sarcoma. *Eur J Surg Oncol*. 2010;36(5):477-482. doi:10.1016/j.ejso.2009.12.005
135. Littrup PJ, Aoun HD, Adam B, Krycia M, Prus M, Shields A. Percutaneous cryoablation of hepatic tumors: long-term experience of a large U.S. series. *Abdom Radiol (NY)*. 2016;41(4):767-780. doi:10.1007/s00261-016-0687-x
136. Koelblinger C, Strauss S, Gillams A. Outcome after radiofrequency ablation of sarcoma lung metastases. *Cardiovasc Intervent Radiol*. 2014;37(1):147-153. doi:10.1007/s00270-013-0644-9
137. Palussiere J, Italiano A, Descat E, et al. Sarcoma lung metastases treated with percutaneous radiofrequency ablation: results from 29 patients. *Ann Surg Oncol*. 2011;18(13):3771-3777. doi:10.1245/s10434-011-1806-0
138. Sato T, Iguchi T, Hiraki T, et al. Radiofrequency ablation of pulmonary metastases from sarcoma: single-center retrospective evaluation of 46 patients. *Jpn J Radiol*. 2017;35(2):61-67. doi:10.1007/s11604-016-0601-z
139. Cazzato RL, Garnon J, Jennings JW, Gangi A. Interventional management of malignant bone tumours. *J Med Imaging Radiat Oncol*. 2023;67(8):862-869. doi:10.1111/1754-9485.13587
140. Howard LE, De Hoedt AM, Aronson WJ, et al. Do skeletal-related events predict overall survival in men with metastatic castration-resistant prostate cancer? *Prostate Cancer Prostatic Dis*. 2016;19(4):380-384. doi:10.1038/pcan.2016.26
141. Tsuya A, Kurata T, Tamura K, Fukuoka M. Skeletal metastases in non-small cell lung cancer: a retrospective study. *Lung Cancer*. 2007;57(2):229-232. doi:10.1016/j.lungcan.2007.03.013
142. Ryan A, Byrne C, Pusceddu C, Buy X, Tsoumakidou G, Filippiadis D. CIRSE standards of practice on thermal ablation of bone tumours. *Cardiovasc Intervent Radiol*. 2022;45(5):591-605. doi:10.1007/s00270-022-03126-x
143. Tomasian A, Jennings JW. Percutaneous minimally invasive thermal ablation of osseous metastases: evidence-based practice guidelines. *AJR Am J Roentgenol*. 2020;215(2):502-510. doi:10.2214/ajr.19.22521
144. Swarm RA, Paice JA, Anghelescu DL, et al. Adult Cancer Pain, Version 3.2019, NCCN Clinical Practice Guidelines in Oncology. *J Natl Compr Canc Netw*. 2019;17(8):977-1007. doi:10.6004/jnccn.2019.0038
145. Goetz MP, Callstrom MR, Charboneau JW, et al. Percutaneous image-guided radiofrequency ablation of painful metastases involving bone: a multicenter study. *J Clin Oncol*. 2004;22(2):300-306. doi:10.1200/jco.2004.03.097
146. Di Staso M, Zugaro L, Gravina GL, et al. A feasibility study of percutaneous radiofrequency ablation followed by radiotherapy in the management of painful osteolytic bone metastases. *Eur Radiol*. 2011;21(9):2004-2010. doi:10.1007/s00330-011-2133-3
147. Callstrom MR, Dupuy DE, Solomon SB, et al. Percutaneous image-guided cryoablation of painful metastases involving bone: multicenter trial. *Cancer*. 2013;119(5):1033-1041. doi:10.1002/cncr.27793
148. Levy J, David E, Hopkins T, et al. Radiofrequency ablation provides rapid and durable pain relief for the palliative treatment of lytic bone metastases independent of radiation therapy: final results from the OsteoCool tumor ablation post-market study. *Cardiovasc Intervent Radiol*. 2023;46(5):600-609. doi:10.1007/s00270-023-03417-x
149. Levy J, Hopkins T, Morris J, et al. Radiofrequency ablation for the palliative treatment of bone metastases: outcomes from the multicenter OsteoCool tumor ablation post-market study (OPuS One study) in 100 patients. *J Vasc Interv Radiol*. 2020;31(11):1745-1752. doi:10.1016/j.jvir.2020.07.014
150. Callstrom MR, Kurup AN. Percutaneous ablation for bone and soft tissue metastases—why cryoablation? *Skeletal Radiol*. 2009;38(9):835-839. doi:10.1007/s00256-009-0736-4
151. McMenomy BP, Kurup AN, Johnson GB, et al. Percutaneous cryoablation of musculoskeletal oligometastatic disease for complete remission. *J Vasc Interv Radiol*. 2013;24(2):207-213. doi:10.1016/j.jvir.2012.10.019
152. Erie AJ, Morris JM, Welch BT, et al. Retrospective review of percutaneous image-guided ablation of oligometastatic prostate cancer: a single-institution experience. *J Vasc Interv Radiol*. 2017;28(7):987-992. doi:10.1016/j.jvir.2017.03.012
153. Wallace AN, Tomasian A, Vaswani D, Vyhmeister R, Chang RO, Jennings JW. Radiographic local control of spinal metastases with percutaneous radiofrequency ablation and vertebral augmentation. *AJNR Am J Neuroradiol*. 2016;37(4):759-765. doi:10.3174/ajnr.a4595
154. Guenette JP, Lopez MJ, Kim E, Dupuy DE. Solitary painful osseous metastases: correlation of imaging features with pain palliation after radiofrequency ablation—a multicenter American College of Radiology Imaging Network study. *Radiology*. 2013;268(3):907-915. doi:10.1148/radiol.13122398
155. Ullrick SR, Hebert JJ, Davis KW. Cryoablation in the musculoskeletal system. *Curr Probl Diagn Radiol*. 2008;37(1):39-48. doi:10.1067/j.cpradiol.2007.05.001
156. Sewell PE, Dhillon GS. Percutaneous MRI guided cryosurgery of bone tumors. *Radiology*. 2002;225:514.
157. Jennings JW, Prologo JD, Garnon J, et al. Cryoablation for palliation of painful bone metastases: the MOTION multicenter study. *Radiol Imaging Cancer*. 2021;3(2):e200101. doi:10.1148/rycan.2021200101
158. Sgalambro F, Zugaro L, Bruno F, et al. Interventional radiology in the management of metastases and bone tumors. *J Clin Med*. 2022;11(12):3265. doi:10.3390/jcm11123265

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