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ORIGINAL RESEARCH

Real-World Analysis of Multidisciplinary Roles in the Management of Hepatocellular Carcinoma: The Mayo Clinic Experience

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Background: Hepatocellular carcinoma (HCC) is a complex disease best managed through multidisciplinary care, yet real-world patterns of medical specialty involvement remain poorly characterized. This study mapped specialty care pathways for HCC patients treated at the three Mayo Clinic destination medical centers.

Methods: A retrospective review was performed using the Mayo Data Explorer for treatments delivered between May 2020 and May 2025. Patients with HCC were identified through diagnosis codes or hepatology consultation. Therapeutic events across interventional radiology (IR), medical oncology, transplant surgery, radiation oncology, and hepatopancreatobiliary surgery (HPBS) were analyzed descriptively by treatment line and Barcelona Clinic Liver Cancer (BCLC) stage.

Results: Of 6051 HCC patients identified, 4799 met inclusion criteria. Hepatology provided consultation for 87% of patients (n=4183). For first-line treatments (n=3079), 37% received initial therapy from IR, 27% from medical oncology, 17% from transplant surgery, 10% from HPBS, and 9% from radiation oncology. IR remained the most common provider across subsequent treatment lines. Analyses were based on treatment events, and some patients contributed to multiple treatment lines. Among patients with documented BCLC stage (n = 906), IR most frequently delivered initial therapy for stages 0 and A, whereas medical oncology predominated for stages B and C. Locoregional therapies were used in 27% of BCLC C patients.

Conclusion: This real-world mapping reveals IR as a procedural cornerstone within multidisciplinary HCC management, particularly for early-stage disease. Hepatology remains essential for initial patient evaluation and care coordination. Medical oncology predominates for intermediate-stage disease, while locoregional therapy continues to be used in a substantial proportion of advanced-stage cases. These findings highlight the complex and evolving role of subspecialties in the management of HCC and may inform future resource allocation and care strategies.

Keywords: interventional radiology, medical oncology, radiation oncology, transplant, hepatopancreatobiliary surgery, hepatocellular carcinoma, multidisciplinary care

Introduction

Hepatocellular carcinoma (HCC) is the most common primary liver malignancy and ranks as the third leading cause of cancer-related death globally, with more than 900,000 new cases and over 830,000 deaths reported annually.[1,2] In the United States, the incidence of HCC has tripled over the past three decades, with approximately 41,000 new cases in 2024.[3]

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Management of HCC is challenging due to the dual hazard of cancer and underlying liver disease, along with the need to coordinate care across multiple oncology subspecialties that offer numerous therapeutic strategies. Care pathways are commonly established at multidisciplinary tumor boards where selection depends on tumor phenotype and biology, hepatic substrate, center resources and expertise, and patient performance status and comorbidities. The Barcelona Clinic Liver Cancer (BCLC) staging system is used as a general guideline to classify patients and allocate treatment; however, clinical nuance, regional expertise, patient preferences, and access to specialty care all influence decision-making.[4] Furthermore, significant deviations from BCLC recommendations have been reported when the above-mentioned patient characteristics are accounted for.[5] All patients are generally considered for curative intent, such as ablation, resection, or transplantation, whereas palliative intent offered to patients who are not candidates.[6] Downstaging to curative options remains a priority in patients who demonstrate favorable initial treatment response.

Since the approval of combination systemic therapy with atezolizumab and bevacizumab in 2020, the treatment landscape has further diversified, expanding the roles of both procedural and medical specialties.[2,4] Prior studies within the Veterans Affairs (VA) system and other single-center registries have demonstrated that multidisciplinary evaluation improves treatment access and outcomes or examined treatment patterns across limited specialties.[7,8] However, these analyses did not delineate how specific specialties contribute to care delivery over time or how patients transition between all treating specialties.

Understanding these patterns is essential to identifying opportunities for improved coordination, refinement of tumor board structures, optimization of multidisciplinary workflows, and supporting alignment with societal and guideline recommendations.

The present study aimed to map real-world specialty utilization and treatment sequencing in HCC care across three Mayo Clinic liver transplantation sites by identifying which specialties initiate and continue care across treatment lines and BCLC stages. This work builds on prior studies by analyzing event-level specialty transitions, providing a process-level view of how multidisciplinary management is operationalized in contemporary practice.

Methods

A retrospective review was conducted using the Mayo Data Explorer (MDE) (Mayo Clinic, Rochester, MN, USA), a tri-site electronic database of Mayo Clinic patients. The study was approved by the Institutional Review Board of Mayo Clinic (protocol number 19–00980), which waived the requirement for informed consent due to the retrospective and de-identified nature of the data. All patients diagnosed with HCC using International Classification of Disease (ICD)-10 code C22.0 and at least one documented therapeutic intervention or hepatology consultation were included. Procedures were identified using a comprehensive list of Current Procedural Terminology (CPT) codes obtained from departmental coders in interventional radiology (IR), medical oncology, transplant surgery, hepatopancreatobiliary surgery (HPBS), and radiation oncology (Table 1). The study period included treatments extracted from the MDE between May 2020 and

Table 1 List of Codes Used in Procedure Search

Category	Code	Description
HCC	ICD-10 C22.0	Malignant neoplasm of hepatocytes
IR	CPT 47382	Percutaneous MWA or RFA
	CPT 47383	Percutaneous cryoablation
	CPT 0600T	IRE or PEF ablations
	CPT 37243	TAE for general tumor embolization- includes TACE and bland embolization
	CPT 79445	Intra-arterial particulate administration for TARE, Y90
	CPT 0686T	Histotripsy of malignant hepatocellular tissue

(*Continued*)

Table 1 (Continued).

Category	Code	Description
Transplant	CPT 47135	Orthotopic Liver Transplant
HPBS	CPT 47120	Hepatectomy, resection of liver; partial lobectomy
	CPT 47122	Trisegmentectomy
	CPT 47125	Total left lobectomy
	CPT 47130	Total right lobectomy
	CPT 47379	Laparoscopic HCC resections
Medical Oncology	CPT 96409	Systemic therapy administration; single or initial substance/drug
	CPT 96411	Systemic therapy administration; each additional substance/drug
	CPT 96413	Systemic therapy administration, IV infusion; single or initial substance/drug
	CPT 96415	Systemic therapy administration, IV infusion; each additional hour
	CPT 96417	Systemic therapy administration, IV infusion; each sequential infusion (different drug)
Radiation Oncology	CPT 77373	Stereotactic body radiotherapy
	CPT 77385	Intensity modulated radiation therapy
	CPT 77412	External beam radiation therapy
	CPT 77525	Proton beam therapy

Abbreviations: IRE, irreversible electroporation; HCC, hepatocellular carcinoma; HPBS, hepatopancreatobiliary surgery; IR, interventional radiology; MWA, microwave ablation; PEF, pulsed electrical field; RFA, radiofrequency ablation; TAE, transcatheter arterial embolization; TACE, transarterial chemoembolization; TARE, transarterial radioembolization.

May 2025. The start date of the study period corresponds to FDA approval of the current systemic therapy standard-of-care (Atezolizumab plus Bevacizumab, Genentech, Inc., South San Francisco, CA, USA).[2] The collected data included a patient numerical identifier, birthdate, sex, procedure description, and procedure date. Patients with incomplete medical records were excluded from the study.

Keyword searches within the MDE were used to extract additional data such as oral systemic treatments, BCLC stage, and the presence of a hepatology consultation. For oral systemic treatments, keyword searches included the drug names: "Sorafenib" (Bayer HealthCare Pharmaceuticals, Whippany, NJ, USA), "Lenvatinib" (Eisai Co., Ltd., Tokyo, Japan), "Cabozantinib" (Exelixis, Inc., Alameda, CA, USA), and "Regorafenib" (Bayer HealthCare Pharmaceuticals Inc., Whippany, NJ, USA). Clinical staging was extracted via keyword search terms such as "BCLC A", "BCLC B", etc. For hepatology consultations, service codes were used to identify whether patients had received at least one consultation note from the hepatology service within the duration of the study. Manual review of all records was performed by a single reviewer (FZI) to confirm the accuracy of keyword-derived data fields, including staging and medication use. Following data extraction, data cleaning and processing were performed in MATLAB (MathWorks, Natick, MA, USA) and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). For transarterial radioembolization (TARE) procedures, mapping angiograms were excluded from the analysis as these are diagnostic and part of the pre-treatment workflow.

Descriptive statistics were used to summarize patient demographics, specialty involvement, and treatment sequencing. Categorical variables were reported as frequencies and percentages. Given the retrospective nature of the data and heterogeneity in clinical documentation, this study was designed as an exploratory analysis without comparative statistics. The distribution of treatment modalities was assessed both by number of patients and by total number of treatments administered. Specialty transitions were analyzed across treatment lines (first, second, third or greater) and

stratified by BCLC stage where available. This study was designed as a descriptive process analysis and inferential statistics were intentionally not performed to avoid overinterpretation of non-comparative data.

Specialty utilization and sequencing were analyzed with regards to both treatment events and unique patients. Lines of treatment, specialty flows, and IR-specific treatment analyses were based on treatment events. Analyses of BCLC staging and overall site distribution were done using individual patients counts. Individuals receiving care across multiple specialties or treatment lines may be counted more than once when looking purely at treatment events. A Sankey diagram created with SankeyMATIC (Steve Bogart, open-source browser-based tool) was used to visualize the flow of specialty involvement across successive treatment episodes. Each node represented a medical specialty, and the width of the connecting flows reflected the number of patients transitioning between specialties. Treatments performed outside the three Mayo Clinic destination centers were not included in the analysis.

Results

Cohort Characteristics and Specialty Involvement

Of the 6051 HCC patients identified, 4799 had complete records and were seen by either hepatology, IR, medical oncology, transplant, radiation oncology, or HPBS, with demographics reported in Table 2. Of these, 3079 patients received at least one treatment within the treatment window and were categorized as the first-line treatment cohort. The remaining 1720 patients were identified to have a consultation by hepatology but no treatment recorded within the Mayo system during this period. A total of 87% (n=4183) had a consultation by hepatology recorded within the Mayo system. Because many patients received care from more than one specialty over time, counts across treatment lines reflect treatment events rather than unique patients, and percentages may exceed 100%. Referral patterns between specialties could not be reliably extracted due to inconsistent documentation.

IR predominated across all sequences of treatment. For the first-line treatment cohort, as depicted in Figure 1, 37% of all treatments were performed by IR, followed by 27% by medical oncology, 17% by transplant, 10% by HPBS, and 9% by radiation oncology. Among second-line treatments (n=1236), 41% were by IR, 28% by medical oncology, 16% by transplant, 11% by radiation oncology, and 4% by HPBS. For third-line or further treatments (n=851), 46% were delivered by IR, 29% by medical oncology, 12% by transplant, 11% by radiation oncology, and 2% by HPBS. When transplant procedures were excluded, IR accounted for 45% of first-line treatments. When calculated using the number of

Table 2 Patient Demographics

Characteristic	Overall (n=4799)
Age, median [IQR]	69 years [62, 75]
Sex, n (%)	
Male	3345 (69.7%)
Female	1454 (30.3%)
Race/Ethnicity, n (%)	
White, non-Hispanic	3761 (78.4%)
Black or African American	196 (4.08%)
Asian	213 (4.44%)
Hispanic or Latino	450 (9.38%)
Native American or Alaska Native	64 (1.33%)
Native Hawaiian or Pacific Islander	12 (0.25%)
Other/Unknown	103 (2.14%)

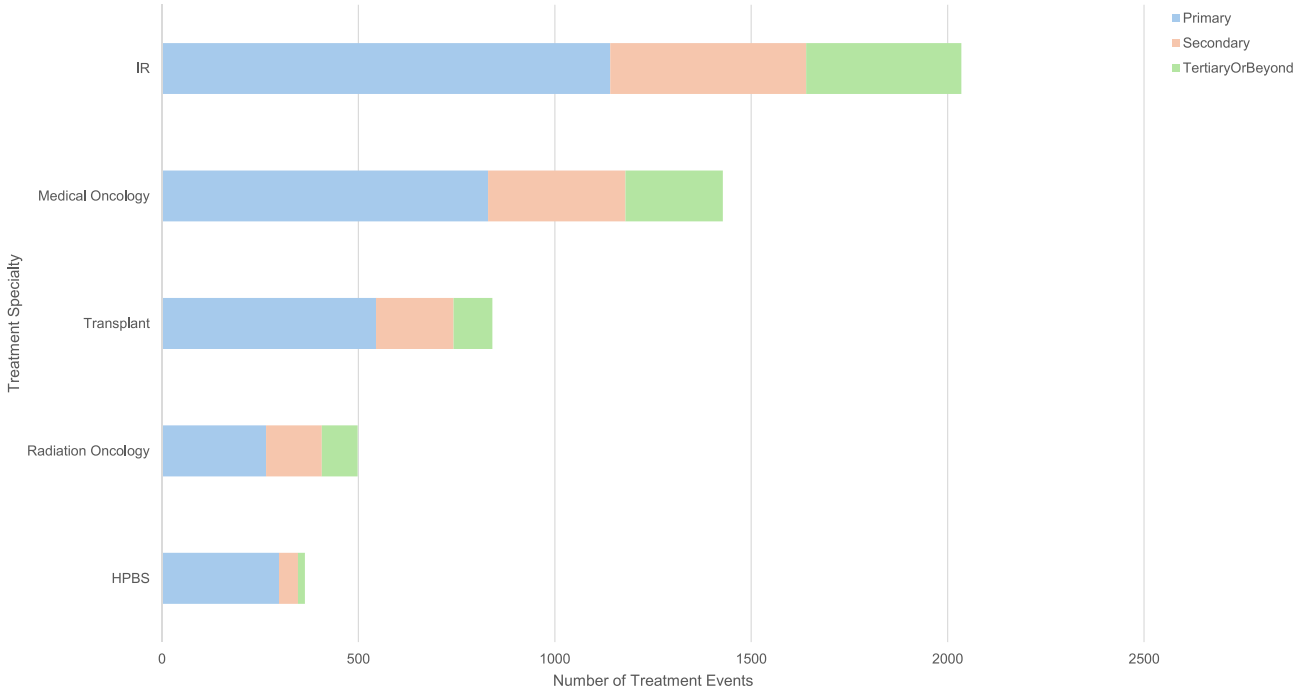

Figure 1 Treatment sequence by therapeutic specialty for hepatocellular carcinoma (HCC) patients from May 2020 to May 2025. Bars represent treatment events rather than unique patients, with each bar segmented by the specialty delivering therapy. The first bar shows the specialty providing initial treatment, and subsequent bars show second-line and third-line or later treatments. Because patients may receive therapies from multiple specialties over time, individuals may be counted across more than one line. Segment height reflects the proportion of all treatments delivered by each specialty within that treatment line, illustrating how specialty involvement shifts across successive phases of care.

patients treated by each specialty as the denominator, the mean number of treatment sessions per patient differed across disciplines: medical oncology patients received an average of 13 sessions, radiation oncology patients 7.6 sessions, interventional radiology patients 1.6 procedures, and HPBS or transplant surgery patients a single intervention.

Treatment Sequencing and Specialty Transitions

Specialty transitions across treatment lines are shown in Figure 2, with wider flow bands indicating more frequent transitions between specialties. Each node represents a treatment event with labels indicating the specialty in which treatment was provided. Among the 1141 patients whose initial treatment was performed by IR, 36% had no additional procedures, while 35% underwent at least one additional IR treatment. Sixteen percent transitioned to transplant surgery, 8% to systemic therapy, 4% to radiation therapy, and 1% underwent subsequent surgical resection by HPBS.

Among patients initially treated with surgical resection (n = 298), 15% later received IR therapies, 13% transitioned to systemic therapy, 6% received radiation therapy, 2% underwent repeat resection, and 1% proceeded to transplant surgery.

The majority of treatment specialties provided primary rather than subsequent treatment except for transplant, with 69% of transplant surgeries being completed after a treatment from another specialty.

Specialty Utilization by BCLC Stage and Across Sites

BCLC stage information was available for 906/4799 patients (18.9%), reflecting non-standardized documentation, and stage-based interpretations should be made with caution, however, given this caveat, specialty involvement was shown to vary by disease stage in this subset (Figure 3). IR was the predominant treatment specialty for very early and early disease, accounting for treatment of 51% of patients in stage 0 and 48% in stage A. In stage B, 48% of patients were treated by medical oncology and 38% by IR. Medical oncology predominated in advanced stages, treating 73% of stage C and 77% of stage D patients. When further analyzing BCLC C, 27% of patients also received some type of locoregional therapy.

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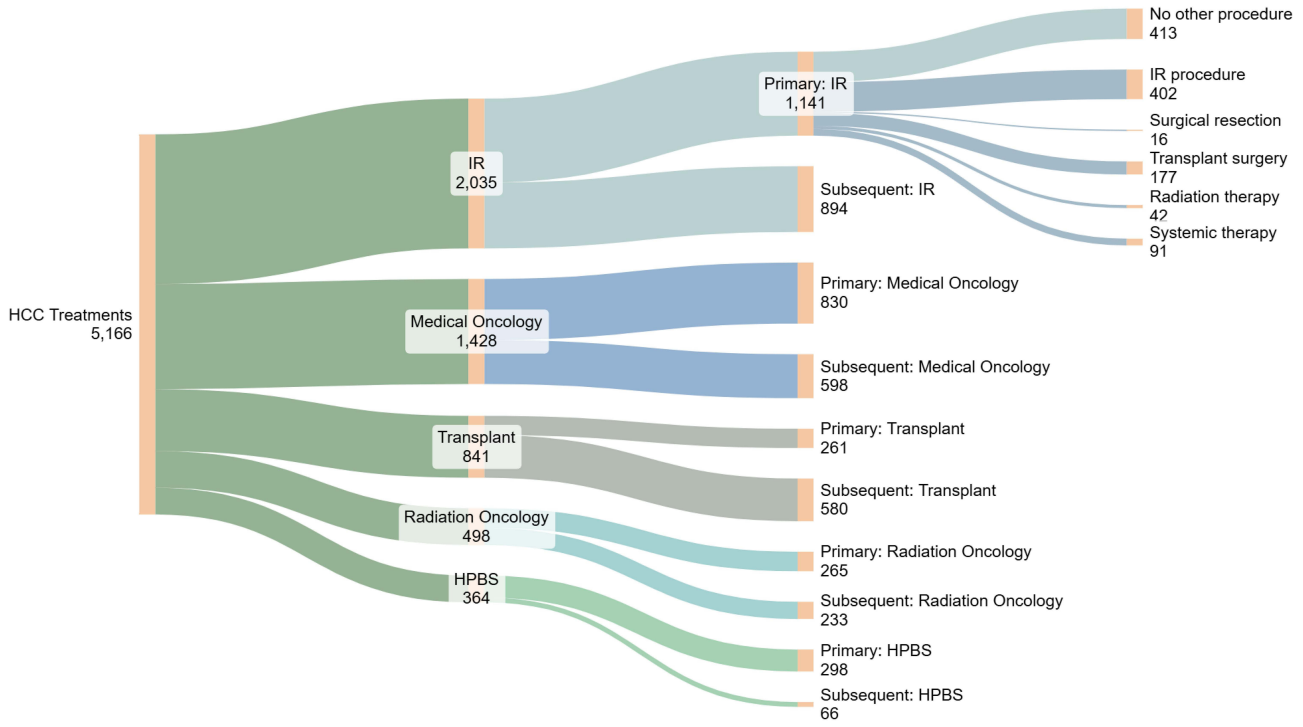

Figure 2 Sankey diagram illustrating transitions between medical specialties involved in HCC treatment from May 2020 to May 2025. Each node represents a treatment event categorized by the specialty providing that therapy. The width of each flow corresponds to the number of patients transitioning from one specialty to another across successive treatment episodes. Primary treatment events appear on the left, with subsequent treatments shown in order moving to the right. Because individual patients may undergo multiple therapies across different specialties, they may be represented in more than one transition pathway. Flows can therefore be interpreted as the relative frequency with which patients progressed from one treating specialty to the next.

Distribution of IR procedures is shown in Figure 4. In event-based analysis of IR-directed therapies, 37% of treatments were radiofrequency ablation (RFA) or microwave ablation (MWA), 33% were transarterial chemoembolization (TACE) or bland transarterial embolization (TAE), and 28% were TARE. Cryoablation, irreversible electroporation, pulsed electrical field therapy, and histotripsy collectively accounted for less than 2% of IR procedures.

Specialty involvement across Mayo Clinic sites is shown in Figure 5. While overall specialty distribution was similar across locations, Arizona had a higher proportion of transplant procedures (18%) compared with Minnesota (5%) and Florida (10%). IR involvement was relatively consistent, representing 18% of treatments in Arizona, 20% in Minnesota, and 25% in Florida. IR procedural patterns also varied across sites (Figure 6). Florida had a higher proportion of TARE compared with Minnesota and Arizona. In contrast, Minnesota and Arizona had the highest proportions of IR-treated patients undergoing ablation, with TACE used more frequently than TARE at both sites.

Discussion

Patterns of medical specialty utilization in the management of HCC are not well described in the literature. This exploratory study characterized real-world multidisciplinary care pathways for a large cohort of HCC patients treated within a destination health system. The findings showed that hepatology was the most frequently seen specialty while IR provided the largest proportion of treatments, both at initial therapy and throughout longitudinal care. Among patients whose first treatment was with IR, over a third required no additional procedural intervention, highlighting the curative capabilities of current locoregional therapies.

The roles of IR and medical oncology have expanded with the increasing use of locoregional therapies such as TARE and immunotherapy-based systemic regimens.[4–6,9,10] Historically, surgical resection and liver transplantation have been regarded as the gold standard treatments for early-stage HCC, however, Parikh et al reported higher use of ablation than resection (59% vs 37%) in this population.[7] Findings from this analysis reflect similar trends, with more than half of patients with BCLC 0 or A receiving IR-directed therapy. Although some patients undergo ablation as a bridge to

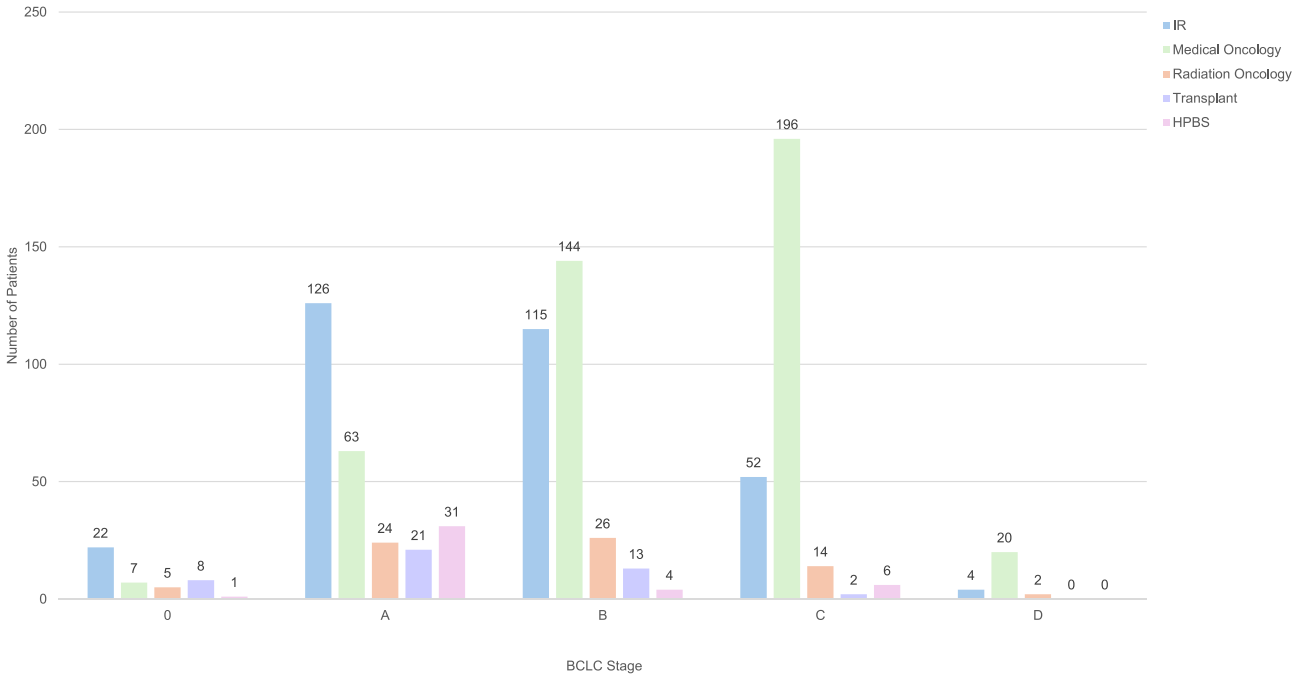

Figure 3 Distribution of patients by treatment specialty across Barcelona Clinic Liver Cancer (BCLC) stages for HCC patients with stage recorded from May 2020 to May 2025. Patient distribution between stages is as follows: stage 0 (n=43), stage A (n=265), stage B (n=302), stage C (n=270), and stage D (n=26). IR predominated in treating patients in very early (stage 0) and early-stage (stage A) disease. Medical oncology was the primary treating specialty in intermediate (stage B), advanced (stage C), and terminal (stage D) stages.
Abbreviations: BCLC, Barcelona Clinic Liver Cancer; IR, interventional radiology; HPBS, hepatopancreatobiliary surgery.

transplantation, this pattern may also indicate growing confidence in ablation as a definitive therapy for appropriately selected early-stage cases, consistent with evolving data, guideline updates, and increasing institutional expertise.[9,11]

Specialty distribution across BCLC stages further demonstrated shifting practice patterns. Systemic therapies represented the majority of treatments in advanced and terminal stages, however, locoregional therapies were also offered in 27% of BCLC C cases. Additionally, nearly half of BCLC B patients (48%) received care from medical oncology. These findings reflect the broader incorporation of systemic therapies earlier in the disease course, particularly for intermediate-stage patients who are suboptimal candidates for TACE or ablation due to tumor burden or liver function, as well as select advanced-stage patients treated with the goal of downstaging to curative options.[9] As reported by Singal et al, substantial treatment heterogeneity exists within BCLC stage groups, and the specialty variations observed here mirror that complexity.[5]

Beyond descriptive mapping, these findings suggest several actionable implications for multidisciplinary HCC care. The consistent predominance of interventional radiology across treatment lines and disease stages supports its role as a core, permanent member of HCC tumor boards rather than a consultative service engaged selectively. In addition, the high rate of initial treatment by medical oncology in BCLC B and C disease, coupled with continued use of locoregional therapy in a substantial subset of advanced-stage patients, highlights the potential value of standardized early co-evaluation by hepatology and medical oncology, with procedural input as indicated. Such parallel assessment may facilitate timely treatment sequencing, preserve opportunities for downstaging, and reduce delays inherent to serial referral models. Finally, observed cross-site differences in specialty utilization and interventional radiology modality selection underscore how process-level mapping can inform local workflow design, staffing, and tumor board composition based on institutional practice patterns.

Cross-site analysis revealed notable differences in specialty involvement across Mayo Clinic locations. Arizona demonstrated a higher proportion of patients undergoing transplantation compared with Florida and Minnesota. Differences were also observed within IR practices, with Florida having greater utilization of TARE, whereas ablation constituted the highest proportion of IR treatments in Minnesota and Arizona. These variations likely reflect institutional

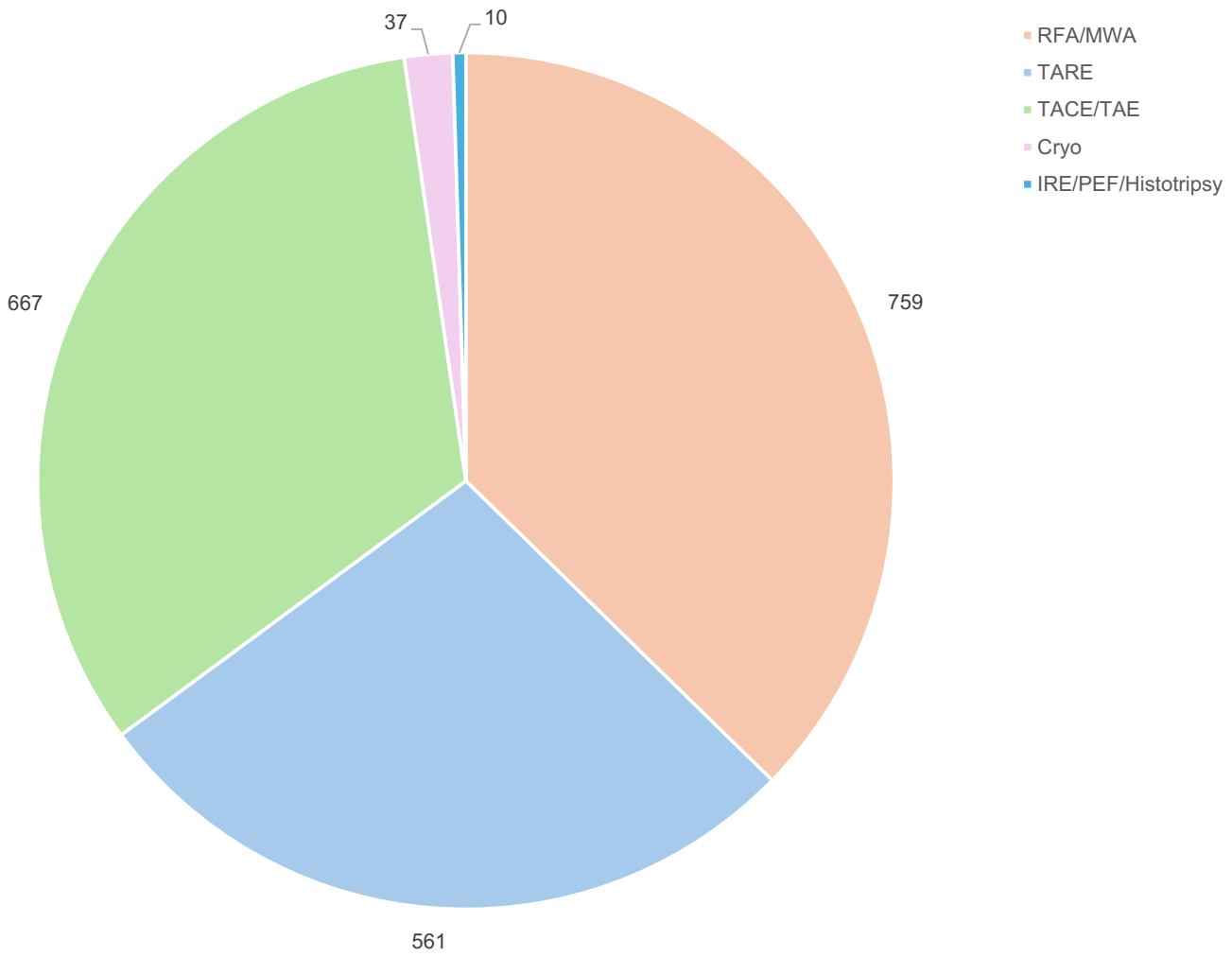

Figure 4 Interventional Radiology (IR) treatment modalities for HCC from May 2020 to May 2025. Thermal ablation, including radiofrequency and microwave ablation, was the most frequently used modality, followed by transarterial chemoembolization or bland embolization (TACE/TAE) and transarterial radioembolization (TARE). Cryoablation, irreversible electroporation (IRE), pulsed electrical field (PEF) therapy, and histotripsy represented a small minority of treatments.
Abbreviations: IR, interventional radiology; TARE, transarterial radioembolization; TACE, transarterial chemoembolization; TAE, transarterial embolization; IRE, irreversible electroporation; PEF, pulsed electrical field therapy.

preferences, transplant program volume, local referral patterns, and differences in multidisciplinary decision-making across sites.

The findings in this study align with prior evidence highlighting the impact of multidisciplinary involvement on treatment utilization and outcomes in HCC. In a national Veterans Affairs cohort, Serper et al demonstrated that patients evaluated by multiple specialties, particularly hepatology, oncology, or surgery, within 30 days of diagnosis were significantly more likely to receive active treatment and had lower mortality compared to those without coordinated specialty care.[8] This underscores that timely, structured interaction between specialties not only reflects guideline-concordant management but also directly influences access to curative or disease-modifying therapies. This analysis expands on prior observations by mapping specialty transitions over time, offering a real-world view into how specialty coordination occurs in practice. These process-level data provide a foundation to identify inefficiencies in referral pathways, streamline multidisciplinary workflows, and support earlier access to definitive treatment.

This study has several limitations. As a retrospective analysis conducted within tertiary referral and transplant centers, practice patterns likely reflect characteristics unique to a destination medical system and may not be generalizable to community settings. Treatment provided before presentation to Mayo Clinic was not captured, limiting assessment of initial therapy selection. BCLC staging was documented for only a subset of patients, likely due to inconsistent structured

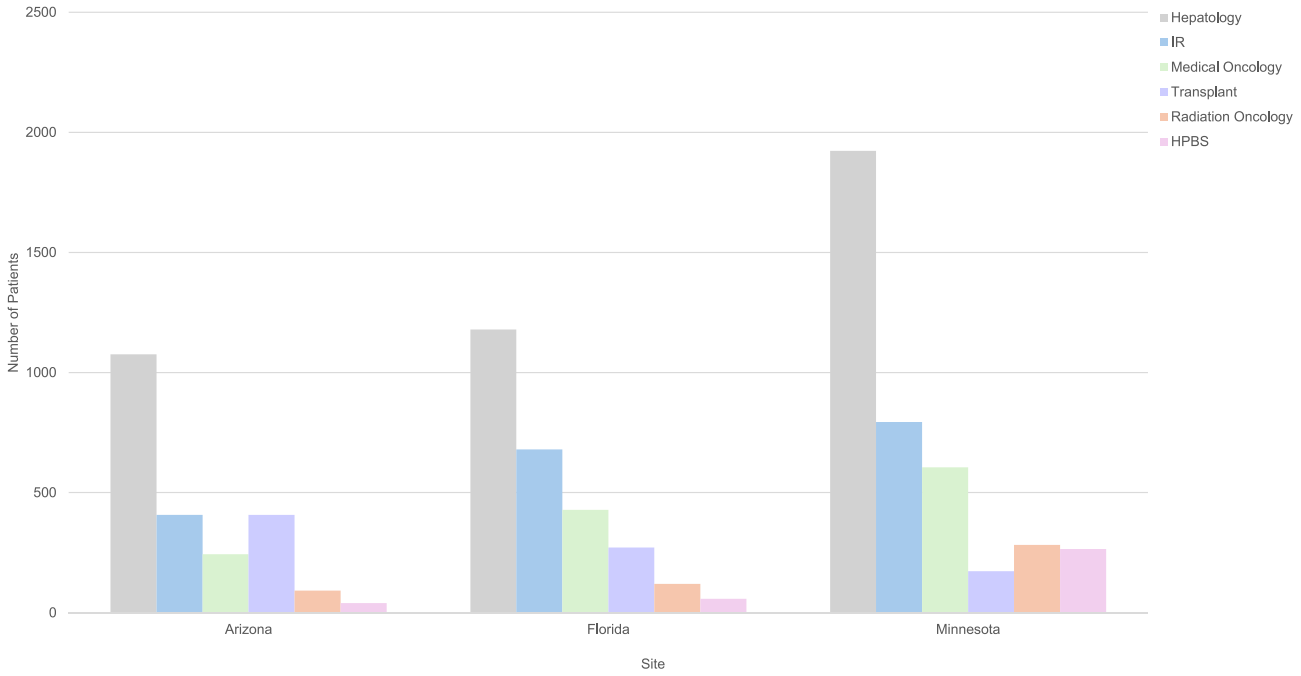

Figure 5 Distribution of hepatocellular carcinoma (HCC) patients treated between May 2020 and May 2025 across Mayo Clinic sites—Rochester, Minnesota (RST); Jacksonville, Florida (FLA); and Scottsdale, Arizona (ARZ). Overall specialty distribution was similar across sites, though Arizona had a higher proportion of transplant procedures. IR involvement was consistent across locations.
Abbreviations: HPBS, hepatopancreatobiliary surgery; IR, interventional radiology; MO, medical oncology; RO, radiation oncology; TRX, transplant surgery.

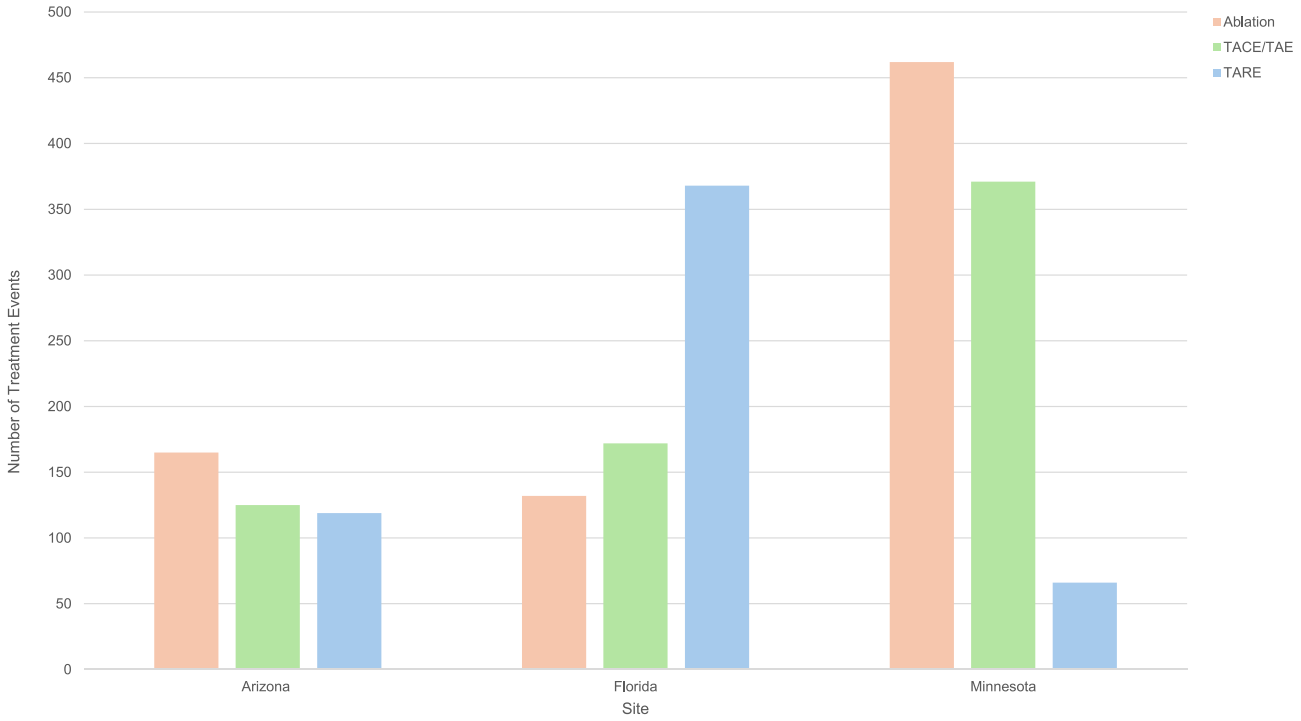

Figure 6 Tri-site distribution of interventional radiology (IR) procedures for hepatocellular carcinoma (HCC) from May 2020 to May 2025. Bars display the proportion of each IR modality, ablation, transarterial chemoembolization or bland embolization (TACE/TAE), and transarterial radioembolization (TARE), performed at each Mayo Clinic site. TARE represented the largest proportion of IR treatments in Florida, whereas ablation constituted the highest proportion in Minnesota and Arizona. Procedural distribution in Arizona was more evenly balanced across modalities.
Abbreviations: IR, interventional radiology; TARE, transarterial radioembolization.

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documentation, which restricts stage-stratified analyses and introduces potential selection bias. Reliance on administrative codes and keyword-based extraction introduces risk of misclassification despite manual review efforts. Referral pattern data could not be extracted due to inconsistent documentation, limiting evaluation of care coordination efficiency. Finally, this descriptive, exploratory analysis did not examine survival, recurrence, or time-to-treatment outcomes. Future work incorporating outcome data will be essential to evaluate how care pathways translate into patient-level results.

Conclusion

This study provides a real-world mapping of multidisciplinary HCC care pathways, underscoring the central roles of hepatology, interventional radiology, and medical oncology across the treatment continuum. As the therapeutic landscape continues to evolve, structured collaboration among procedural, medical, and surgical disciplines remains essential. The consistent involvement of interventional radiology supports its role as a core tumor board discipline, while the early and sustained participation of medical oncology in intermediate and advanced disease suggests potential benefit from coordinated hepatology–medical oncology evaluation early in the disease course. These findings may inform broader care models by identifying specialty sequencing patterns that enhance coordination beyond tertiary centers, guiding tumor board composition, workflow optimization, and resource planning. Future research should link these specialty pathways with clinical outcomes and explore machine learning tools to predict optimal treatment flows; for example, using these data to develop a decision-support tool that can optimize initial specialty involvement and sequencing based on a patient's presenting characteristics, thereby supporting more precise and personalized HCC care.

Abbreviations

BCLC, Barcelona Clinic Liver Cancer; CPT, Current Procedural Terminology; HCC, hepatocellular carcinoma; IR, interventional radiology; IRE, irreversible electroporation; PEF, pulsed electrical field; TACE, transarterial chemoembolization; TAE, transarterial embolization; TARE, transarterial radioembolization.

Ethical Considerations

This study complies with the Declaration of Helsinki.

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Disclosure

LRR has been on advisory boards for AstraZeneca, Bayer, Eisai, Exact Sciences, Focus Medical Communication, Gilead Sciences, GRAIL, Inc., Novartis Venture Fund, Pontifax, and Roche. BBT is a consultant for AstraZeneca, Boston Scientific, Genentech, Eisai, Sirtex, Replimune, ABK, BD, Terumo, Galvanize, Turnstone Biologics, Johnson and Johnson, HistoSonics, and Vivos; in addition, Dr Beau B Toskich has a patent 19/186,015 licensed to Assigned to Mayo Clinic. RJL is a consultant for Boston Scientific, BD, Varian, and AstraZeneca and is president elect of the Society of Interventional Radiology (SIR). Umair Majeed reports grants from AstraZeneca, during the conduct of the study. Kris Croome is an Advisory Board in Bridge to Life, during the conduct of the study. Dr Amit Mathur is an Advisory Board in Specialist Direct Inc, outside the submitted work. The authors report no other conflicts of interest in this work.

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