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ORIGINAL RESEARCH ARTICLE

Predictors of survival after transarterial radioembolization in patients with hepatocellular carcinoma

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Abstract

Introduction: Transarterial radioembolization with yttrium-90–based microspheres (TARE) is an established therapy for patients with advanced non-metastatic hepatocellular carcinoma (HCC). However, factors associated with short or long survival are not completely clear.

Objectives: To examine a cohort of patients not candidates for surgery who were treated with TARE and had known survival duration to document and compare the characteristics of those with shorter versus longer survival times.

Methods: HCC patients ($n = 308$) were treated exclusively with TARE and followed until death. Their baseline and follow-up blood clinical parameters were retrospectively analyzed. Patients were categorized into short-term (<11 months) and long-term (>11 months) survivors according to the cohort median survival.

Results: The longer- and shorter-survival groups differed significantly in maximum tumor diameter (MTD), multifocality, portal vein thrombosis (PVT), albumin-bilirubin (ALBI), modified ALBI, platelet-ALBI grades, alpha-fetoprotein (AFP), albumin, liver function parameters, and C-reactive protein. In multivariable logistic regression, MTD, multifocality, AFP, albumin, and hemoglobin had significant odds ratios. Patients with PVT were represented in both survival groups. In the longer-survival PVT group, multifocality was significantly less frequent, and MTD, platelet-ALBI grade, aspartate aminotransferase, gamma-glutamyl transferase, and C-reactive protein were lower, while albumin was higher. Increased albumin post-TARE was significantly associated with increased survival, independent of baseline AFP. Patients with normal bilirubin in the total cohort were dichotomized by albumin level. Lower albumin was associated with poorer survival and higher baseline inflammation markers, with no change in tumor factors. Increased albumin or decreased AFP post-TARE were each associated with increased survival.

Conclusion: Baseline tumor and inflammation parameters were independently associated with survival post-TARE, as were increased albumin and decreased AFP in response to TARE.

Keywords: Hepatocellular carcinoma; Radioembolization; Inflammation; Biomarkers; Survival

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1. Introduction

Yttrium-90 radioactive particle transarterial radioembolization (TARE) has been increasingly used as a frontline therapy for non-metastatic hepatocellular carcinoma (HCC), owing to its safety and efficacy.[1-3] Its role is also evolving as results from new combinations of TARE with kinase inhibitors and immune checkpoint inhibitors become available.[4-6] However, it is not yet clear which patient subgroups benefit most from TARE therapy, although suggestions include radiological response, alpha-fetoprotein (AFP) response, segmental treatment, and radiomics, even in the presence of portal vein thrombosis (PVT).[7-11] Many studies involve downstaging to curative resection or transplantation.[12-14] In the present study, HCC patients were followed up after TARE as their only therapy. Based on their survival, two groups of patients were identified, with different clinical characteristics. The aims of this study are to identify survival markers and examine changes in inflammatory markers in response to TARE that might affect survival. We hypothesized that baseline tumor characteristics, liver function, and inflammatory biomarkers might identify patients with markedly different survival following TARE. Notably, we found that responses to TARE, not just baseline values, were significantly associated with increased survival in patients with high or low baseline AFP levels. These results suggest that baseline-only parameters may be prognostically tentative until TARE responses can be evaluated.

2. Methods

2.1. Clinical data

This study followed 308 patients with non-surgically treatable, non-metastatic HCC treated with TARE for changes in serum AFP and routine hematology and liver function tests.

Demographic, clinical characteristics, laboratory results, and abdominal computed axial tomography scans were analyzed for baseline maximum tumor diameter (MTD), tumor numbers, and the presence or absence of macroscopic PVT by tumor. Baseline and follow-up serum AFP levels, liver function tests, and complete blood count values were measured. Albumin-bilirubin (ALBI) grade for HCC, modified ALBI (mALBI), and platelet-ALBI (PALBI) grades were calculated (www.mdcalc.com).

The diagnosis of HCC was established through percutaneous biopsy or noninvasively based on the presence of a hepatic mass greater than 2 cm in diameter with characteristic imaging findings in the setting of liver cirrhosis as per European Association for the Study of the Liver (EASL) guidelines. Treatment was performed on an inpatient basis, and patients were typically not discharged home until 24 h after the procedure to allow for post-TARE safety observations.

Inclusion criteria were patients with diagnosed non-metastatic HCC who were considered to be ineligible for definitive surgical treatment, age ≥18 years, a lung shunt <20%, prior informed consent for the radioembolization procedure and treatment; Eastern Cooperative Oncology Group (ECOG) performance status ≤3, and adequate hematologic, renal, and liver function tests for a safe interventional procedure.

2.2. Radioembolization procedures

Patients were treated as per published guidelines[15] and as we previously reported.[16] They underwent pre-treatment angiographic mapping of the abdominal aorta and hepatic arteries. Planar scans of the lung and liver area in anterior and posterior views were acquired after injection of 99mTc-labeled macroaggregated albumin (99mTc-MAA) into selected arterial branches, followed by single-photon emission computed tomography (SPECT) or SPECT/computed tomography (CT) scans. Radioembolization was delivered using yttrium-90 resin microspheres (SIR-Spheres; Sirtex Medical Limited, Australia) or glass microspheres (Therasphere, Boston Scientific, United States of America [USA]). Personalized dosimetry planning, considering optimal absorbed doses using tumoral and non-tumoral volumes, was used by the treating interventional radiologist for dose calculation.

2.3. Statistical methods

The normality of the quantitative data was assessed using Kolmogorov–Smirnov and Shapiro–Wilk tests. Continuous data are summarized as median (minimum–maximum). Comparisons between two independent samples were performed using the Mann–Whitney *U* test. For more than two independent groups, the Kruskal–Wallis test and Conover's pairwise comparison test were used. Categorical data are presented as frequency (percentage) and were compared using the Pearson chi-square test (asymptotic or exact significance, where appropriate), continuity-corrected chi-square test, or Fisher's exact test, depending on the assumptions. When the omnibus test was significant for more than two groups, pairwise comparisons were performed using the Bonferroni correction. In all tables, superscript letters represent the results of pairwise comparisons. The approximate median survival time determined using the Kaplan–Meier method was used to identify short-term (≤11 months) and long-term (>11 months) survivors rather than applying an arbitrary clinical threshold, and to ensure balanced distribution between groups to maintain maximum statistical power

and avoid parameter estimation bias from class imbalance. To identify predictors of short-term survival, univariate logistic regression was applied as a first step. Independent predictors of short-term survival were identified using multivariable logistic regression with a backward stepwise elimination method based on the likelihood ratio criterion (backward: LR). All potential candidate variables were initially included in the full model. Variables were iteratively removed from the model if their likelihood ratio statistics were ≥0.10, while a threshold of $p < 0.05$ was applied for variable entry/retention in the final model. Receiver operating characteristic (ROC) analysis was used to obtain the best cutoff value based on the Youden index for continuous variables. In all analyses, a two-sided significance level of 0.05 was accepted. SPSS 26.0 (IBM Corp., USA) was used for statistical analyses.

3. Results

3.1. Survival post-TARE

All patients in this study received radioembolization as the only treatment for their non-surgical, advanced, and non-metastatic HCC. Table 1 and Figure 1 depict their survival, showing a mean of 22.72 ± 1.77 months and a median of 11.30 ± 1.24 months. The cumulative proportion surviving at 12 months was 0.477 ± 0.028 (under 50%), while the proportions surviving at 24 and 60 months were 0.269 ± 0.025 (under 30%) and 0.096 ± 0.021 (under 10%), respectively. Figure 1 suggests two cumulative survival groupings, one with a sharp decrease in survival (shorter-survival group) and the other with a gentler, more prolonged slope (longer-survival group). The approximate median survival time of the total cohort (11 months) was used as the cutoff value.

The two survival groups were then compared. The median survival was 25.63 ± 1.78 months for the longer-survival group and 4.43 ± 0.39 months for the shorter-survival group (Table 2, Figure 2). We then compared the groups by clinical characteristics, as shown for categorical (Table 3) and continuous (Table 4) parameters. Significant differences were observed in parameters such as MTD, multifocality, PVT, ALBI, mALBI, and PALBI grades (Table 3). Significant differences in continuous variables were observed in parameters such as levels of AFP, MTD, albumin, gamma-glutamyl transferase (GGT), aspartate aminotransferase AST), alanine aminotransferase (ALT), alkaline phosphatase (ALKP), hemoglobin, and C-reactive protein (CRP), as shown in Table 4. Interestingly, neither neutrophil-to-lymphocyte ratio (NLR) nor platelet-to-lymphocyte ratio (PLR) was significantly different. Odds ratios (OR) were significant in univariate logistic regression analyses for all the liver function parameters, hemoglobin, MTD, and almost for AFP ($p = 0.053$). The highest ORs were from ALBI and mALBI (OR for each 56.640), PALBI (OR 10.089), multifocality (OR 4.904), MTD (OR 3.453), and PVT (OR 3.138), as shown in Table 3.

We used ROC analysis to identify short-duration survivors (Table 5). All parameters were significant in univariable logistic regression analysis, with the highest ORs from MTD, GGT, albumin, CRP, and ALKP (all >4.0), as well as AFP (OR 3.695). The cutoffs were used to perform a multivariable logistic regression analysis for short-term survival (≤11 months) versus long-term survival (>11 months), shown in Table 6. Significant parameters were MTD (OR 4.088), AFP (OR 3.829), multifocality (OR 2.937), albumin (OR 2.955), and hemoglobin (OR 2.459).

3.2. Parameter changes post-TARE and survival

It has previously been suggested that parameter changes post-TARE might influence survival. Changes in serum levels of albumin, AFP, and GGT were thus examined in the total cohort, and separately in patients with either high (≥100 IU/mL) or low baseline serum AFP (<100 IU/mL) levels (Tables 7–9). We found that the percentage of patients with stable or increased levels of albumin post-TARE was significantly higher in the longer-survival group compared with the shorter-survival group, measured at 1, 3, or 6 months post-TARE. Decreased or stable AFP levels were observed in a significantly higher percentage of patients in the longer-survival group than in the shorter-survival group with elevated baseline AFP levels. In patients with lower baseline serum AFP levels, a higher percentage had decreased or stable AFP levels in the longer-survival group, but this was not significant except at six months post-TARE. Survival did not differ significantly in patients with stable or decreased GGT values post-TARE.

3.3. Portal vein thrombosis

Portal vein thrombosis was present in 44.8% of long survivors and 55.2% of short survivors (Table 3). We therefore evaluated clinical differences between PVT-positive patients in the short-survival and long-survival groups (Tables 10 and 11), since PVT is one of the most potent poor-prognosis factors for HCC survival. The significantly different categorical variables were multifocality and PALBI grade, although MTD showed a trend, with 39.6% of PVT patients having MTD >6 cm in the longer-survival group and 60.4% in the shorter-survival group ($p = 0.095$). Significant differences in continuous variables were found between the two PVT survival groups for AFP, MTD, GGT, AST, ALKP, albumin, and CRP values. Thus, tumor parameters (MTD, multifocality, AFP), liver parameters (PALBI, albumin), and inflammation parameters (AST, CRP) were different between the two

Table 1. Total cohort survival post-TARE (N = 308)

Time point (months)	Number at risk	Number of cumulative events	Cumulative proportion surviving at the time ± SE	Survival (months)	
				Mean ± SE	Median ± SE
12	147	161	0.477 ± 0.028		
24	78	224	0.269 ± 0.025		
36	39	251	0.165 ± 0.022	22.72 ± 1.77	11.30 ± 1.24
48	20	257	0.136 ± 0.021		
60	11	262	0.096 ± 0.021		

Abbreviation: TARE: Transarterial radioembolization.

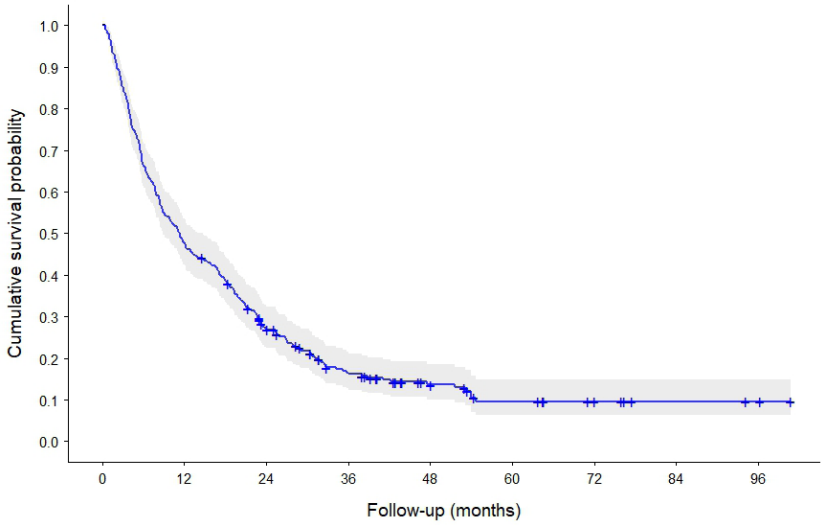


Figure 1. Cumulative survival of the total cohort

Table 2. Subgroup survival post-TARE

Time point (months)	Number at risk	Number of cumulative events	Cumulative proportion surviving at the time ± SE	Survival (months)	
				Mean ± SE	Mean ± SE
Survival ≤11 months (n = 151)					
1	144	8	0.947 ± 0.018		
2	126	26	0.828 ± 0.031	4.88 ± 0.23	4.43 ± 0.39
3	105	46	0.695 ± 0.037		
6	48	105	0.305 ± 0.037		
9	12	139	0.079 ± 0.022		
Survival >11 months (n = 157)					
12	147	10	0.936 ± 0.019		
24	78	73	0.528 ± 0.040	39.88 ± 2.86	25.63 ± 1.78
36	39	100	0.324 ± 0.040		
48	20	106	0.266 ± 0.039		
60	11	111	0.189 ± 0.041		

Abbreviation: TARE: Transarterial radioembolization.

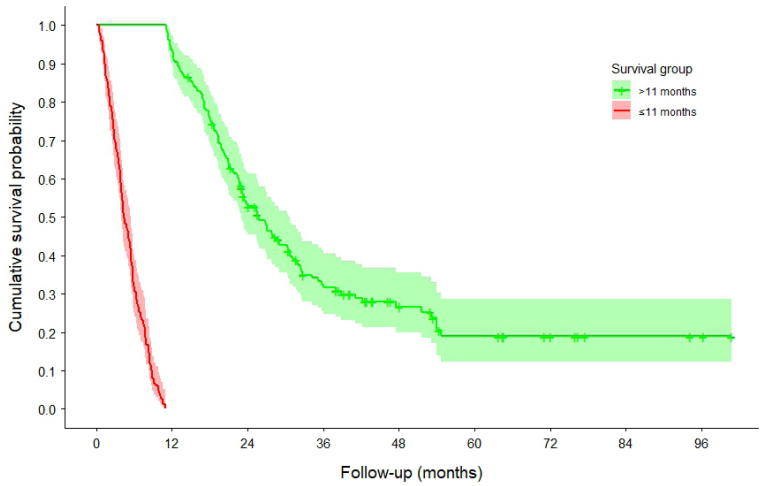


Figure 2. Cumulative survival of subgroups

Table 3. Comparison of categorical parameters between survival groups

Variable	Category	Survival		*p*	Univariate logistic regression (OR [95% CI])	*p*
		>11 months	≤11 months			
Gender	Male	133 (48.7)	136 (51.3)	0.185	Reference	
	Female	24 (61.5)	15 (38.5)		0.594 (0.299–1.181)	0.137
HBV	No	52 (45.2)	63 (54.8)	0.153	Reference	
	Yes	103 (53.6)	89 (46.4)		0.713 (0.448–1.134)	0.153
HCV	No	149 (50.3)	147 (49.7)	1.000	Reference	
	Yes	6 (54.5)	5 (45.5)		0.845 (0.252–2.828)	0.784
MTD (cm)	≤3	14 (70.0)	6 (30.0)[ab]	<0.001	Reference	
	3–6	38 (80.9)	9 (19.1)[b]		0.553 (0.166–1.837)	0.333
	>6	25 (40.3)	37 (59.7)[a]		3.453 (1.170–10.196)	0.025
PVT	No	51 (71.8)	20 (28.2)	0.003	Reference	
	Yes	26 (44.8)	32 (55.2)		3.138 (1.510–6.523)	0.002
Multifocality	No	39 (81.3)	9 (18.8)	<0.001	Reference	
	Yes	38 (46.9)	43 (53.1)		4.904 (2.104–11.427)	<0.001
ALBI grade	1	59 (70.2)	25 (29.8)[a]	<0.001	Reference	
	2	97 (47.8)	102 (52.2)[b]		2.579 (1.499–4.438)	0.001
	3	1 (4.0)	24 (96.0)[c]		56.640 (7.260–441.885)	<0.001
mALBI grade	1	59 (70.2)	25 (29.8)[a]	<0.001	Reference	
	2a	40 (59.7)	27 (40.3)[ab]		1.593 (0.810–3.132)	0.177
	2b	57 (41.9)	79 (58.1)[b]		3.271 (1.834–5.834)	<0.001
	3	1 (4.0)	24 (96.0)[c]		56.640 (7.260–441.885)	<0.001
PALBI grade	1	59 (73.8)	21 (26.3)[a]	<0.001	Reference	
	2	76 (58.0)	55 (42.0)[a]		2.033 (1.108–3.731)	0.022
	3	22 (21.8)	79 (78.2)[b]		10.089 (5.078–20.044)	<0.001

Note: Different superscript letters in the same column indicate statistically significant differences among the categories of the row variable.
Abbreviations: ALBI: Albumin-bilirubin; HBV: Hepatitis B virus; HCV: Hepatitis C virus; mALBI: Modified ALBI; MTD: Maximum tumor diameter; OR: Odds ratio; PALBI: Platelet-ALBI; PVT: Portal vein thrombosis.

Table 4. Comparison of continuous parameters between survival groups

Variable	*n*	Survival >11 months (median [min–max])	*n*	Survival ≤11 months (median [min–max])	*p*
AFP (IU/mL)	153	19.9 (0–175,137.8)	155	448.5 (1.6–141,582.8)	<0.001
MTD (cm)	77	4.7 (0.86–14.9)	52	8.9 (0.7–16.9)	<0.001
T. Bili (mg/dL)	155	0.9 (0.2–2.8)	153	1.1 (0.22–8.1)	<0.001
Albumin (g/dL)	155	3.8 (2.5–5.2)	153	3.3 (1.7–5.0)	<0.001
GGT (IU/mL)	155	78 (13–1,258)	153	158 (19–1,328)	<0.001
AST (IU/mL)	155	37 (14–217)	153	52 (11–407)	<0.001
ALT (IU/mL)	155	31 (9–434)	153	37 (6–672)	0.011
ALKP (IU/mL)	155	103 (38–533)	153	154 (48–528)	<0.001
Hb (g/dL)	155	14.0 (6.7–108.0)	153	13.4 (3.8–18.8)	0.015
Platelets ($\times 10^9$/L)	155	155 (24–691)	153	167 (43–702)	0.150
CRP (mg/L)	92	0.37 (0.30–43.00)	100	1.44 (0.30–20.00)	<0.001
NLR	156	2.65 (0.77–23.54)	152	3.12 (0.41–26.82)	0.154
PLR	156	111.87 (2.05–842.00)	152	124.53 (14.26–1,048.72)	0.095

Abbreviations: AFP: Alpha-fetoprotein; Alb: Albumin; ALBI: Albumin-bilirubin; ALKP: Alkaline phosphatase; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; CRP: C-reactive protein; GGT: Gamma-glutamyltransferase; Hb: Hemoglobin; mALBI: Modified ALBI; MTD: Maximum tumor diameter; NLR: Neutrophil-to-lymphocyte ratio; PALBI: Platelet-ALBI; PLR: Platelet-to-lymphocyte ratio; PVT: Portal vein thrombosis; T. Bili: Total bilirubin.

Table 5. ROC analysis for determining short-duration survivors

Variable	Best cutoff	Youdenindex	Sensitivity (95% CI)	Specificity (95% CI)	AUC		Univariate logistic regression	
					Mean (95% CI)	*p*-value	OR (95% CI)	*p*-value
MTD (cm)	>6.6	0.39	69.23 (54.90–81.30)	70.13 (58.60–80.00)	0.701 (0.614–0.779)	<0.001	5.283 (2.459–11.350)	<0.001
AFP (IU/mL)	>274.19	0.30	54.55 (46.30–62.60)	75.48 (67.90–82.00)	0.676 (0.620–0.728)	<0.001	3.695 (2.276–5.997)	<0.001
GGT (IU/mL)	>101	0.33	70.97 (63.10–78.00)	62.42 (54.30–70.00)	0.714 (0.660–0.763)	<0.001	4.060 (2.528–6.522)	<0.001
Alb (g/dL)	≤3.3	0.31	51.61 (43.50–59.70)	78.98 (71.80–85.10)	0.708 (0.654–0.758)	<0.001	4.008 (2.439–6.586)	<0.001
CRP (mg/L)	>1.03	0.37	64.00 (53.80–73.40)	72.83 (62.60–81.60)	0.684 (0.613–0.749)	<0.001	4.764 (2.577–8.809)	<0.001
ALKP (IU/mL)	>135	0.36	62.58 (54.50–70.20)	73.25 (65.60–80.00)	0.721 (0.667–0.770)	<0.001	4.579 (2.833–7.403)	<0.001
AST (IU/mL)	>41	0.27	67.10 (59.10–74.40)	59.87 (51.80–67.60)	0.673 (0.618–0.725)	<0.001	3.043 (1.916–4.833)	<0.001
ALT (IU/mL)	>40	0.17	45.81 (37.80–54.00)	71.34 (63.60–78.30)	0.583 (0.526–0.638)	0.010	2.104 (1.317–3.361)	0.002
T. Bili (mg/dL)	>1.05	0.17	53.59 (45.40–61.70)	63.46 (55.40–71.00)	0.611 (0.554–0.666)	<0.001	2.069 (1.368–3.128)	0.001
Hb (g/dL)	≤13.8	0.15	61.94 (53.80–69.60)	53.50 (45.40–61.50)	0.580 (0.523–0.635)	0.014	1.872 (1.193–2.940)	0.006

Abbreviations: AFP: Alpha-fetoprotein; Alb: Albumin; ALKP: Alkaline phosphatase; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; AUC: Area under the curve; CRP: C-reactive protein; GGT: Gamma-glutamyltransferase; Hb: Hemoglobin; MTD: Maximum tumor diameter; OR: Odds ratio; ROC: Receiver operating characteristic; T. Bili: Total bilirubin.

Table 6. Multivariable logistic regression analysis for short-term survival (≤11 months) versus long-term survival (>11 months)

Variable	Category	Multivariable logistic regression (OR [95% CI])	*p*
Multifocality	No	Reference	
	Yes	2.937 (1.102–7.829)	0.031
AFP (IU/mL)	≤274.19	Reference	
	>274.19	3.829 (1.581–9.275)	0.003
MTD (cm)	≤6.6	Reference	
	>6.6	4.088 (1.692–9.876)	0.002
Albumin (g/dL)	>3.3	Reference	
	≤3.3	2.955 (1.019–8.565)	0.046
Hemoglobin (g/dL)	>13.8	Reference	
	≤13.8	2.459 (1.003–6.027)	0.049

Abbreviations: AFP: Alpha-fetoprotein; MTD: Maximum tumor diameter; OR: Odds ratio.

survival groups, suggesting that factors other than the presence of PVT alone may modulate survival in patients with PVT.

3.4. Characteristics of patients with different baseline serum albumin and normal bilirubin

The ALBI, mALBI, and PALBI parameters reflect liver function and are based on albumin and total bilirubin levels.[17-19] In order to examine the effects of changes in serum albumin in the absence of abnormal serum bilirubin, we examined tumor characteristics and deaths in patients with normal or decreased serum albumin levels, all of whom had normal total bilirubin levels (<1.2 mg/dL). As shown in Table 12, the low-albumin subcohort had a significantly higher death rate than the high-albumin subcohort (<3.5g/dL) over the duration of this study. To understand the reasons, we examined tumor parameters. MTD was higher in the shorter-survival group compared to the longer-survival group (8.25 cm versus 5.85 cm), but not significantly ($p = 0.090$; Table 12). Multifocality, serum AFP, and the percentage of patients with PVT did not differ significantly between the two albumin subcohorts. In contrast, AST, GGT, ALKP, international normalized ratio (INR), NLR, PLR, and CRP were all significantly higher in the low-albumin (lower survival) subcohort. These results suggest that albumin-based survival differences are associated with differences in liver and inflammation indices (AST, GGT, CRP, NLR, PLR), but not with tumor indices (MTD, focality, PVT, AFP).

4. Discussion

This cohort of HCC patients was treated with locoregional therapy (TARE) since they were not eligible for liver resection or liver transplant, based on MTD, multifocality, the presence of PVT, AFP, or because they were unwilling or there was no organ available. The principal findings of this study are that survival following TARE is independently associated with baseline tumor burden, liver function, systemic inflammation, serum albumin, and AFP responses to TARE.

As shown in Table 1 and Figure 1, we identified two survival groups: >11 months and ≤11 months. The medians of these two survival groups are shown in Table 2: 25.63 ± 1.78 and 4.43 ± 0.39 months, respectively. We examined the reasons for these survival differences by comparing the clinical characteristics (Tables 3 and 4). There were significant differences between the two survival groups based on tumor parameters (MTD, tumor focality, PVT, and AFP levels), liver parameters (ALBI, mALBI, PALBI, and almost all liver function tests), and inflammation parameters (AST, GGT, CRP, and almost PLR; with $p = 0.095$). The survival groups thus reflected traditional causes of death in HCC, namely liver and tumor factors and inflammation, as reflected in the Glasgow Index.[20-24] To further examine the prognostic factors, an ROC analysis was performed to determine the best cutoff values for individual factors (Table 5), and these were then used to perform a multivariate logistic regression analysis for short-term (≤11 months) versus long-term survival (>11

Table 7. Albumin changes post-TARE

Group		Albumin changes from baseline (*n* [%])		
		Survival >11 months	Survival ≤11 months	*p*
Total cohort				
1 month	Increased/Stable	145 (55.8)	115 (44.2)	<0.001
	Decreased	0 (0)	12 (100)	
3 months	Increased/Stable	125 (69.1)	56 (30.9)	<0.001
	Decreased	2 (11.8)	15 (88.2)	
6 months	Increased/Stable	111 (84.7)	20 (15.3)	<0.001
	Decreased	5 (31.3)	11 (68.8)	
12 months	Increased/Stable	88 (98.9)	1 (1.1)	1.000
	Decreased	13 (100)	0 (0)	
AFP < 100 IU/mL subcohort				
1 month	Increased/Stable	94 (67.1)	46 (32.9)	0.039
	Decreased	0 (0)	3 (100)	
3 months	Increased/Stable	82 (74.5)	28 (25.5)	0.048
	Decreased	2 (33.3)	4 (66.7)	
6 months	Increased/Stable	80 (88.9)	10 (11.1)	0.049
	Decreased	4 (57.1)	3 (42.9)	
12 months	Increased/Stable	57 (98.3)	1 (1.7)	1.000
	Decreased	7 (100)	0 (0)	
AFP ≥ 100 IU/mL subcohort				
1 month	Increased/Stable	49 (41.9)	68 (58.1)	0.012
	Decreased	0 (0)	9 (100)	
3 months	Increased/Stable	42 (60.9)	27 (39.1)	0.001
	Decreased	0 (0)	11 (100)	
6 months	Increased/Stable	30 (75)	10 (25)	0.002
	Decreased	1 (12.5)	7 (87.5)	
12 months	Increased/Stable	30 (100)	–	NA
	Decreased	6 (100)	–	

Abbreviations: AFP: Alpha-fetoprotein; NA: Not available; TARE: Transarterial radioembolization.

Table 8. AFP changes post-TARE

Group		AFP changes from baseline (*n* [%])		
		Survival >11 months	Survival ≤11 months	*p*
AFP < 100 IU/mL subcohort				
1 month	Increased/Stable	47 (66.2)	24 (33.8)	0.675
	Decreased	42 (71.2)	17 (28.8)	
3 months	Increased/Stable	40 (74.1)	14 (25.9)	0.951
	Decreased	36 (76.6)	11 (23.4)	
6 months	Increased/Stable	49 (94.2)	3 (5.8)	0.046
	Decreased	27 (79.4)	7 (20.6)	
12 months	Increased/Stable	35 (97.2)	1 (2.8)	1.000
	Decreased	22 (95.7)	1 (4.3)	
AFP ≥ 100 IU/mL subcohort				
1 month	Increased/Stable	40 (44.9)	49 (55.1)	0.025
	Decreased	5 (18.5)	22 (81.5)	
3 months	Increased/Stable	32 (64.0)	18 (36.0)	0.011
	Decreased	5 (26.3)	14 (73.7)	
6 months	Increased/Stable	25 (71.4)	10 (28.6)	1.000
	Decreased	6 (66.7)	3 (33.3)	
12 months	Increased/Stable	26 (100)	–	NA
	Decreased	7 (100)	–	

Abbreviations: AFP: Alpha-fetoprotein; NA: Not available; TARE: Transarterial radioembolization.

months). As shown in Table 6, only 5 parameters were significant: 3 tumor factors (MTD, AFP, and multifocality, in order of their odds ratios) and 2 inflammation factors (albumin and hemoglobin). Given the importance of albumin and ALBI in prognosis, we were particularly interested in whether changes in albumin or the tumor biomarker AFP in consequence of TARE therapy might have additional prognostic usefulness. Tables 7–9 show the changes in albumin and two HCC biomarkers (AFP and GGT) post-TARE in relation to survival. Stable or increased albumin levels were significantly associated with longer survival, regardless of serum AFP levels (Table 7). This is useful in clinical practice, as more than 40% of HCC patients do not have elevated AFP levels, and thus the identification of another HCC biomarker is helpful in guiding patient care and decision-making. Responses (decreases) in serum AFP levels to TARE therapy were also found to significantly relate to better survival, but only in patients with elevated baseline AFP levels (Table 8). Survival was also longer in patients with lower AFP levels who had a decrease or stable albumin, but not significantly. Changes in serum GGT levels did not relate at all to survival (Table 9). The results show that both baseline tumor and serum factors, as well as albumin and AFP level response to TARE therapy, are useful predictors of longer survival in TARE-treated HCC patients.

It is noteworthy that although PVT is among the most important predictors of poor survival in HCC patients, it was present in 44.8% of long survivors and 55.2% of short survivors (Tables 3 and 4). Although there were significantly more in the shorter-survival cohort, the clinical characteristics of HCC patients with PVT were compared for the shorter-survival group versus the longer-survival group (Tables 10 and 11). The longer-survival cohort had significantly fewer patients with multifocality and higher PALBI (Table 10, categorical parameters) and significantly fewer patients with high MTD or AFP tumor factors, or higher GGT, AST, ALKP, or lower albumin liver factors (Table 11). CRP values were also significantly lower in the longer-survival group. These results suggest that even in patients with PVT, survival is influenced by higher levels of tumor, liver, and inflammatory factors. Taking this into account suggests that patients with PVT who might

Table 9. GGT changes post TARE

Group		GGT changes from baseline (*n* [%])		
		Survival >11 months	Survival ≤11 months	*p*
AFP < 100 IU/mL subcohort				
1 month	Increased/Stable	55 (64.0)	31 (36.0)	0.710
	Decreased	39 (68.4)	18 (31.6)	
3 months	Increased/Stable	61 (74.4)	21 (25.6)	0.779
	Decreased	23 (69.7)	10 (30.3)	
6 months	Increased/Stable	59 (86.8)	9 (13.2)	1.000
	Decreased	25 (86.2)	4 (13.8)	
12 months	Increased/Stable	46 (97.9)	1 (2.1)	1.000
	Decreased	18 (100)	0 (0)	
AFP ≥ 100 IU/mL subcohort				
1 month	Increased/Stable	29 (36.7)	50 (63.3)	0.821
	Decreased	19 (40.4)	28 (59.6)	
3 months	Increased/Stable	27 (50.9)	26 (49.1)	0.878
	Decreased	15 (55.6)	12 (44.4)	
6 months	Increased/Stable	21 (75.0)	7 (25.0)	0.139
	Decreased	10 (50.0)	10 (50.0)	
12 months	Increased/Stable	22 (100)	–	NA
	Decreased	14 (100)	–	

Abbreviations: AFP: Alpha-fetoprotein; GGT: Gamma-glutamyltransferase; NA: Not available; TARE: Transarterial radioembolization.

not otherwise be considered for aggressive HCC therapy due to their general poor prognosis might indeed benefit from cancer therapy if they have parameters similar to those in the longer-survival group, as shown in Tables 10 and 11.

Given the prognostic importance of ALBI and its derivatives, as well as albumin, we decided to examine the effects of albumin, given its reported direct actions on HCC biology.[25-27] The total cohort was therefore re-examined, but only in patients with normal total bilirubin levels and then dichotomized by albumin values (Table 12). Survival was significantly longer in patients with normal albumin. Interestingly, none of the tumor factors were significantly different between the two survival groups. However, the longer-surviving patients had significantly lower AST, GGT, and CRP levels, as well as NLR and PLR, all of which are markers of inflammation. Despite normal total bilirubin, there were significant differences in INR, suggesting liver dysfunction.[28] Overall, these results highlight the importance of inflammation in HCC patient survival, as Virchow[29] reported over 160 years ago, rather than focusing mainly on tumor determinants. This approach of identifying both baseline and TARE-induced changes in serum factors is particularly useful in patient management, given that patients come to our tertiary center for definitive therapy when possible but often do not return for follow-up scans due to geographic and resource limitations. This approach has been built upon reports by others of baseline prognostic factors for patients receiving TARE therapy and on tumor responses to TARE.[30-35] The results reported here generally agree with other findings and also show that very early (1 month) improvements in AFP and albumin are significantly associated with improved survival, whether baseline AFP levels are elevated or low. Similar findings were observed for GGT levels, but they did not reach significance. Our independent predictors of multifocality, PVT, AFP, and ALBI/albumin are fully concordant with the results of others.[30-34]

Table 10. Categorical parameters between survival groups in patients with PVT

Parameter	Category	Survival >11 months	Survival ≤11 months	*p*
Gender	Male	20 (41.7)	28 (58.3)	0.319
	Female	6 (60.0)	4 (40.0)	
HBV	No	6 (30.0)	14 (70.0)	0.144
	Yes	20 (54.1)	17 (45.9)	
HCV	No	25 (45.5)	30 (54.5)	1.000
	Yes	1 (50.0)	1 (50.0)	
MTD (cm)	≤3	–	–	0.095
	3–6	7 (70.0)	3 (30.0)	
	>6	19 (39.6)	29 (60.4)	
Multifocality	No	10 (76.9)	3 (23.1)	0.020
	Yes	16 (35.6)	29 (64.4)	
ALBI grade	1	13 (59.1)	9 (40.9)	0.093
	2	13 (39.4)	20 (60.6)	
	3	0 (0)	3 (100)	
mALBI grade	1	13 (59.1)	9 (40.9)	0.112
	2a	7 (50.0)	7 (50.0)	
	2b	6 (31.6)	13 (68.4)	
	3	0 (0)	3 (100)	
PALBI grade	1	13 (61.9)	8 (38.1)[a]	0.013
	2	11 (50.0)	11 (50.0)[ab]	
	3	2 (13.3)	13 (86.7)[b]	

Notes: Data are in *n* (%). Different superscript letters in the same column indicate statistically significant differences among the categories of the row variable.

Abbreviations: ALBI: Albumin-bilirubin; HBV: Hepatitis B virus; HCV: Hepatitis C virus; mALBI: Modified ALBI; MTD: Maximum tumor diameter; PALBI: Platelet-ALBI; PVT: Portal vein thrombosis.

Limitations of this study include its retrospective design, single-center nature, absence of a comparator group, and potential selection bias, as patients were excluded from surgery and patients whose liver function or lung shunt made radioembolization more hazardous were excluded. Furthermore, most patients had hepatitis B, and very few had alcoholism or metabolic dysfunction–associated steatohepatitis. A strength was that we had no treatments other than TARE, and the results suggest a possible role for anti-inflammatory drugs in HCC therapy. Furthermore, not all our subsets had CRP data available, as it was added to routine use only recently. Indeed, patients with versus without CRP could differ, and the CRP associations are therefore susceptible to selection bias and need to be interpreted cautiously. Interestingly, in the albumin-stratified normal-bilirubin analysis (Table 12), NLR and PLR were significantly higher in the low-albumin group, indicating our cohort had NLR/PLR signal.

Table 11. Continuous parameters between survival groups in patients with PVT

Variable	Survival >11 months		Survival ≤11 months		*p*
	n	Median (min–max)	*n*	Median (min–max)	
AFP (IU/mL)	26	11.65 (2.22–76,057.00)	32	2,219.19 (2.53–54,000.00)	<0.001
MTD (cm)	26	8.85 (3.60–14.90)	32	10.65 (3.50–16.90)	0.018
T. Bili (mg/dL)	26	0.85 (0.20–2.40)	32	1.00 (0.40–7.70)	0.079
Albumin (g/dL)	26	3.8 (3.0–4.7)	32	3.6 (2.4–4.9)	0.020
GGT (IU/mL)	26	96.5 (22.0–634.0)	32	157.0 (34.0–715.0)	0.032
AST (IU/mL)	26	41.5 (16.0–200.0)	32	59.0 (19.0–407.0)	0.024
ALT (IU/mL)	26	30.0 (11.0–434.0)	32	34.5 (10.0–264.0)	0.531
ALKP (IU/mL)	26	116.5 (56.0–509.0)	32	155.5 (50.0–446.0)	0.048
Hemoglobin (g/dL)	26	13.90 (7.90–16.40)	32	13.25 (9.70–15.70)	0.063
Platelets ($\times 10^9$/L)	26	209.5 (66.0–486.0)	32	195.0 (43.0–688.0)	0.790
CRP (mg/L)	17	0.45 (0.31–43.00)	23	1.88 (0.30–20.00)	0.017
NLR	26	2.37 (1.15–15.99)	32	3.62 (0.49–19.46)	0.070
PLR	26	127.05 (59.72–328.89)	32	129.13 (29.25–1,048.72)	0.590

Abbreviations: AFP: Alpha-fetoprotein; ALKP: Alkaline phosphatase; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; CRP: C-reactive protein; GGT: Gamma-glutamyltransferase; MTD: Maximum tumor diameter; NLR: Neutrophil-to-lymphocyte ratio; PLR: Platelet-to-lymphocyte ratio; PVT: Portal vein thrombosis; T. Bili: Total bilirubin.

Table 12. Patient characteristics by baseline serum levels of albumin, with normal bilirubin (≤1.2 mg/dL)

Variable	Albumin >3.5 g/dL		Albumin ≤3.5 g/dL		*p*
	n	Median (min–max)	*n*	Median (min–max)	
MTD (cm)	68	5.85 (1.20–16.50)	24	8.25 (2.50–16.90)	0.090
Multifocality (*n* [%])	40	58.8	17	70.8	0.425
AFP (IU/mL)	120	55.30 (0–76.057.00)	85	27.03 (2.10–175,137.80)	0.619
PVT^+ (*n* [%])	31	45.6	12	50.0	0.893
T. Bili (mg/dL)	121	0.80 (0.20–1.20)	86	0.78 (0.22–1.20)	0.942
INR	120	1.09 (0.90–2.58)	85	1.13 (0.90–122.00)	0.017
AST (IU/mL)	121	37 (11–380)	86	47 (14–407)	0.002
GGT (IU/mL)	121	85 (13–681)	86	149 (17–1,258)	<0.001
CRP (mg/L)	78	0.37 (0.30–43.00)	51	2.26 (0.30–20.00)	<0.001
NLR	121	2.26 (0.41–23.54)	85	3.10 (0.49–22.69)	0.002
PLR	121	108.9 (14.26–577.78)	85	146.47 (2.05–936.00)	0.004
Platelets ($\times 10^9$/L)	121	177.0 (30.0–688.0)	86	191.5 (24.0–702.0)	0.544
Deaths (*n* [%])	95	78.5	78	91.8	0.018

Abbreviations: AFP: Alpha-fetoprotein; ALKP: Alkaline phosphatase; AST: Aspartate aminotransferase; CRP: C-reactive protein; GGT: Gamma-glutamyltransferase; INR: International normalized ratio; MTD: Maximum tumor diameter; NLR: Neutrophil-to-lymphocyte ratio; PLR: Platelet-to-lymphocyte ratio; PVT: Portal vein thrombosis; T. Bili: Total bilirubin.

This work highlights the joint contribution of tumor burden, liver function, and systemic inflammation using routinely available serum markers, and the association of early post-TARE albumin/AFP dynamics with survival. We propose that these findings are consistent with the concept that hepatocarcinogens such as chronic viral hepatitis cause chronic inflammation, with HCC as a late consequence, and that a subsequent decrease in serum albumin indirectly reduces survival due to cachexia or loss of control of HCC growth and invasion.

5. Conclusion

These results show that TARE-treated non-surgical HCC patients display two survival trends, each with characteristic clinical parameters. A multivariable regression analysis identified five significant survival-related parameters, namely MTD, AFP, multifocality, albumin, and hemoglobin. Patients with PVT showed two survival groups, mainly related to tumor factors, inflammatory factors, and albumin. Dichotomizing the total cohort of patients with normal total bilirubin by albumin highlighted the independent association between inflammatory markers and survival post-TARE.

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Conflict of interest

The authors declare no conflict of interest.

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Ethics approval and consent to participate

Inonu Transplant Institute database management conforms to Turkish legislation on privacy, and this study conforms to the ethical guidelines of the World Medical Association, Declaration of Helsinki. Inonu University IRB (2025/8125) approved this retrospective analysis of de-identified HCC patients.

Consent for publication

Not applicable.

Availability of data

The data are available from the corresponding author upon reasonable request.

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