Supplementary Table 1. Missing-data profile and complete-case retention.

Variable	Missing/unknown, n	Missing/unknown, %
AJCC stage	4707	15.1
Tumor size	5802	18.6
AFP status	7360	23.5
Full analytic cohort	31274	100.0
Strict complete-case cohort retained	19748	63.1

Stage, tumor size, and AFP status were the variables used to define the strict complete-case set. The full cohort was retained for cumulative-incidence estimation and missing-category sensitivity analysis.

Supplementary Table 2. Assessment of the proportional subdistribution hazards assumption.

Variable	Level	Reference	Covariate-by-log(1+time) coefficient	SE	P value
Age group, years	50-64	18-49	0.047	0.043	0.272
Age group, years	65-74	18-49	0.146	0.049	0.003
Age group, years	≥75	18-49	0.175	0.056	0.002
Sex	Male	Female	0.041	0.039	0.297
Race	Black	White	0.058	0.046	0.210
Race	Asian/Pacific Islander	White	0.065	0.052	0.209
Race	Other	White	0.045	0.123	0.715
AJCC stage	II	I	-0.097	0.040	0.017
AJCC stage	III	I	-0.294	0.060	<0.001
AJCC stage	IV	I	-0.629	0.076	<0.001
Tumor size	>3-5 cm	≤3 cm	-0.098	0.040	0.015
Tumor size	>5-10 cm	≤3 cm	-0.193	0.051	<0.001

Variable	Level	Reference	Covariate-by-log(1+time) coefficient	SE	P value
Tumor size	>10 cm	≤3 cm	-0.499	0.078	<0.001
AFP status	Elevated	Normal	-0.085	0.036	0.018
AFP status	Borderline	Normal	-0.046	0.335	0.890
Surgery	Ablation	No surgery	0.620	0.052	<0.001
Surgery	Resection	No surgery	1.013	0.102	<0.001
Surgery	Transplant	No surgery	0.853	0.120	<0.001
Surgery	Other	No surgery	0.257	0.251	0.306
Chemotherapy	Yes	No/unknown	0.521	0.033	<0.001
Diagnosis period	2014-2015	2010-2013	-0.021	0.033	0.531

Each coefficient represents a covariate-by-log(1 + follow-up months) interaction in the extended Fine-Gray model. The global Wald test was highly significant (chi-square = 836.6, df = 21, $P < 0.001$), supporting presentation of time-specific rather than single constant SHRs.

Supplementary Table 3. Comparison of constant Fine-Gray, full-cohort missing-category, and cause-specific Cox models.

Variable	Level	Reference	Complete-case constant SHR (95% CI)	P value (constant SHR)	Full-cohort missing-indicator SHR (95% CI)	P value (full-cohort SHR)	Cause-specific HR (95% CI)	P value (cause-specific HR)
Age group, years	50-64	18-49	1.12 (1.00-1.25)	0.060	1.05 (0.96-1.15)	0.311	1.14 (1.02-1.28)	0.021
Age group, years	65-74	18-49	1.08 (0.95-1.23)	0.232	1.00 (0.90-1.11)	0.983	1.19 (1.05-1.35)	0.007
Age group, years	≥75	18-49	1.33 (1.15-1.53)	<0.001	1.21 (1.08-1.35)	<0.001	1.69 (1.47-1.95)	<0.001
Sex	Male	Female	1.05 (0.95-1.15)	0.363	1.05 (0.98-1.14)	0.188	1.11 (1.01-1.22)	0.029
Race	Black	White	1.15 (1.02-1.29)	0.021	1.17 (1.07-1.28)	<0.001	1.12 (1.00-1.26)	0.047
Race	Asian/Pacific Island	White	0.78 (0.70-0.88)	<0.001	0.79 (0.72-0.87)	<0.001	0.65 (0.57-0.73)	<0.001

Variable	Level	Reference	Complete-case constant SHR (95% CI)	P value (constant SHR)	Full-cohort missing-indicator SHR (95% CI)	P value (full-cohort SHR)	Cause-specific HR (95% CI)	P value (cause-specific HR)
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Race	Other	White	0.81 (0.59-1.11)	0.193	0.83 (0.65-1.07)	0.149	0.79 (0.58-1.09)	0.151
AJCC stage	II	I	0.78 (0.71-0.86)	<0.001	0.79 (0.72-0.86)	<0.001	0.93 (0.84-1.03)	0.145
AJCC stage	III	I	0.55 (0.48-0.64)	<0.001	0.56 (0.50-0.63)	<0.001	0.89 (0.78-1.02)	0.105
AJCC stage	IV	I	0.36 (0.31-0.43)	<0.001	0.40 (0.36-0.46)	<0.001	0.90 (0.77-1.06)	0.217
Tumor size	>3-5 cm	≤3 cm	0.98 (0.89-1.08)	0.631	0.99 (0.91-1.08)	0.859	1.27 (1.16-1.41)	<0.001
Tumor size	>5-10 cm	≤3 cm	0.84 (0.74-0.95)	0.004	0.84 (0.76-0.93)	<0.001	1.32 (1.17-1.50)	<0.001
Tumor size	>10 cm	≤3 cm	0.63 (0.54-0.	<0.001	0.58 (0.50-0.6	<0.001	1.32 (1.12-1.	0.001

Variable	Level	Reference	Complete-case constant SHR (95% CI)	P value (constant SHR)	Full-cohort missing-indicator SHR (95% CI)	P value (full-cohort SHR)	Cause-specific HR (95% CI)	P value (cause-specific HR)
			75)		7)		56)	
AFP status	Elevated	Normal	0.85 (0.78-0.93)	<0.001	0.84 (0.78-0.91)	<0.001	1.09 (1.00-1.18)	0.051
AFP status	Borderline	Normal	0.64 (0.26-1.55)	0.322	0.67 (0.30-1.50)	0.331	0.74 (0.31-1.79)	0.508
Surgery	Ablation	No surgery	0.95 (0.85-1.07)	0.389	0.98 (0.89-1.08)	0.687	0.58 (0.51-0.65)	<0.001
Surgery	Resection	No surgery	0.62 (0.53-0.74)	<0.001	0.63 (0.55-0.72)	<0.001	0.26 (0.22-0.30)	<0.001
Surgery	Transplant	No surgery	0.72 (0.61-0.86)	<0.001	0.78 (0.68-0.90)	<0.001	0.31 (0.26-0.37)	<0.001
Surgery	Other	No surgery	1.24 (0.72-2.14)	0.431	0.71 (0.51-1.00)	0.050	0.94 (0.54-1.62)	0.815
Chemotherap	Yes	No/unkno	0.77 (0.71-0.	<0.001	0.77 (0.72-0.8	<0.001	0.51 (0.47-0.	<0.001

Variable	Level	Reference	Complete-case constant SHR (95% CI)	P value (constant SHR)	Full-cohort missing-indicator SHR (95% CI)	P value (full-cohort SHR)	Cause-specific HR (95% CI)	P value (cause-specific HR)
y		wn	84)		2)		56)	
Diagnosis period	2014-2015	2010-2013	0.88 (0.81-0.96)	0.003	0.89 (0.83-0.95)	<0.001	0.87 (0.80-0.95)	0.001

The complete-case models included 19,748 patients. The full-cohort model included 31,274 patients and explicit missing categories. Cause-specific HRs treat HCC death as a competing event censored at its occurrence; SHRs model the cumulative incidence of non-HCC death. All models included the listed variables simultaneously. CI: confidence interval; HR: hazard ratio; SHR: subdistribution hazard ratio.