Supplemental Table 1. Clinicopathologic data of training cohort in univariate and multivariate regression analysis

Variable	Univariate analysis			Multivariate analysis		
	HR	**95% CI**	***P* value**	**HR**	**95% CI**	***P* value**
Age (year-old) >65 (38.3%) vs. ≤65 (61.7%)	0.995	0.864~1.147	0.948			
Sex Male (77.4%) vs. Female (22.6%)	1.351	1.137~1.606	0.001	1.392	1.168~1.660	<0.001
Comorbidity[a] Yes (54.2%) vs. No (45.8%)	0.925	0.806~1.061	0.266			
HBV Positive (61.4%) vs. Negative (38.6%)	1.116	0.967~1.287	0.134			
HCV Positive (30.8%) vs. Negative (69.2%)	1.032	0.889~1.2	0.676			
Pre-OP treatment[b] Yes (11.1%) vs. No (88.9%)	1.598	1.304~1.957	<0.001	1.390	1.134~1.705	0.002
ICG R15 >15(16.4%) vs. ≤15(83.6%)	1.302	1.087~1.559	0.004	1.223	1.011~1.481	0.039
ALB(g/dl) >3.5(92.8%) vs. ≤3.5(7.2%)	0.773	0.604~0.99	0.041	0.903	0.695~1.174	0.447
AST(IU/L) 2ULN >68(16.5%) vs. ≤68(83.5%)	1.522	1.28~1.81	<0.001	1.139	0.924~1.403	0.223

ALT(IU/L) 2ULN >72(16.6%) vs. ≤72(83.4%)	1.459	1.228~1.735	<0.001	1.301	1.059~1.598	0.012
ALP (IU/L) >100(22.3%) vs. ≤100(77.7%)	1.547	1.321~1.811	<0.001	1.142	0.966~1.350	0.119
AFP (200ng/mL) >200 (25.0%) vs. ≤200 (75.0%)	1.565	1.345~1.821	<0.001	1.292	1.103~1.514	0.001
OP time (300 minutes) More (37.2%) vs. less (62.8%)	1.318	1.145~1.516	<0.001	0.952	0.811~1.117	0.548
Blood Loss (500ml) More (25.4%) vs. less (74.6%)	1.452	1.247~1.69	<0.001	1.056	0.895~1.246	0.516
Hepatectomy Major (28.9%) vs. Minor (71.1%)	1.664	1.439~1.924	<0.001	1.052	0.884~1.252	0.568
Anatomic resection Yes (41.3%) vs. No (58.7%)	0.918	0.798~1.057	0.234			
Inflow control Yes (68.2%) vs. No (31.8%)	1.419	1.214~1.659	<0.001	1.148	0.976~1.350	0.095
Major complication[c] Yes (26.5%) vs. No (73.5%)	1.427	1.227~1.659	<0.001	1.111	0.950~1.299	0.188
Tumor size (cm) >5.0(30.1%) vs. ≤5.0(69.9%)	2.148	1.863~2.477	<0.001	1.566	1.326~1.850	<0.001
Cirrhosis[d] Yes (47.4%) vs. no (52.6%)	1.236	1.077~1.418	0.003	1.271	1.100~1.469	0.001

Encapsulation Yes (83.9%) vs. no (16.1%)	0.93	0.771~1.122	0.448			
Satellite lesion (%) Yes (5.5%) vs. no (94.5%)	3.203	2.5~4.105	<0.001	1.953	1.515~2.518	<0.001
Margin (cm) <0.5(54.9%) vs. ≥0.5(45.1%)	1.308	1.138~1.504	<0.001	1.198	1.039~1.380	0.013
Vascular invasion (%) Yes (35.0%) vs. No (65.0%)	2.406	2.093~2.765	<0.001	1.849	1.589~2.152	<0.001
Grading I/ II/ III, IV (%) III, IV (38.9%) vs. I, II (61.1%)	1.467	1.276~1.685	<0.001	1.206	1.043~1.393	0.011

HBV hepatitis B virus, *HCV* hepatitis C virus, *ICG R15* indocyanine green retention test at 15 minutes, *ALB* albumin, *AST* aspartate aminotransferase, *ALT* alanine aminotransferase, *ALP* alkaline phosphatase, *AFP* alfa-fetoprotein, *Grade* Edmondson-Steiner grading system

[a]include diabetes mellitus, hypertension, end-stage renal disease, cerebral vascular accident, chronic obstructive pulmonary disease and other.

[b]include ablation, target therapy, immunotherapy, embolization, chemotherapy, radiotherapy, proton therapy, thalidomide and other.

[c]According to the Clavien-Dindo classification, grade 3 and above are considered major complications.

[d]The pathology report demonstrates an Ishak score of F5-F6.

Supplemental Table 2. Details of preoperative treatment received by patients in the training and validation cohort

	Training cohort	**Validation cohort**
RFA/PEIT	37	56
Tyrosine kinase inhibitors[a]	0	39
Immunotherapy[b]	0	5
TACE/TAE	144	54
Chemotherapy[c]	0	7
Radiotherapy	1	18
Proton therapy	0	0
Thalidomide	0	4
Others	4	1
No/Unknow[d]	1495	151

RFA/PEIT radiofrequency ablation or percutaneous ethanol injection therapy; *TACE/TAE* transarterial chemoembolization or transarterial embolization

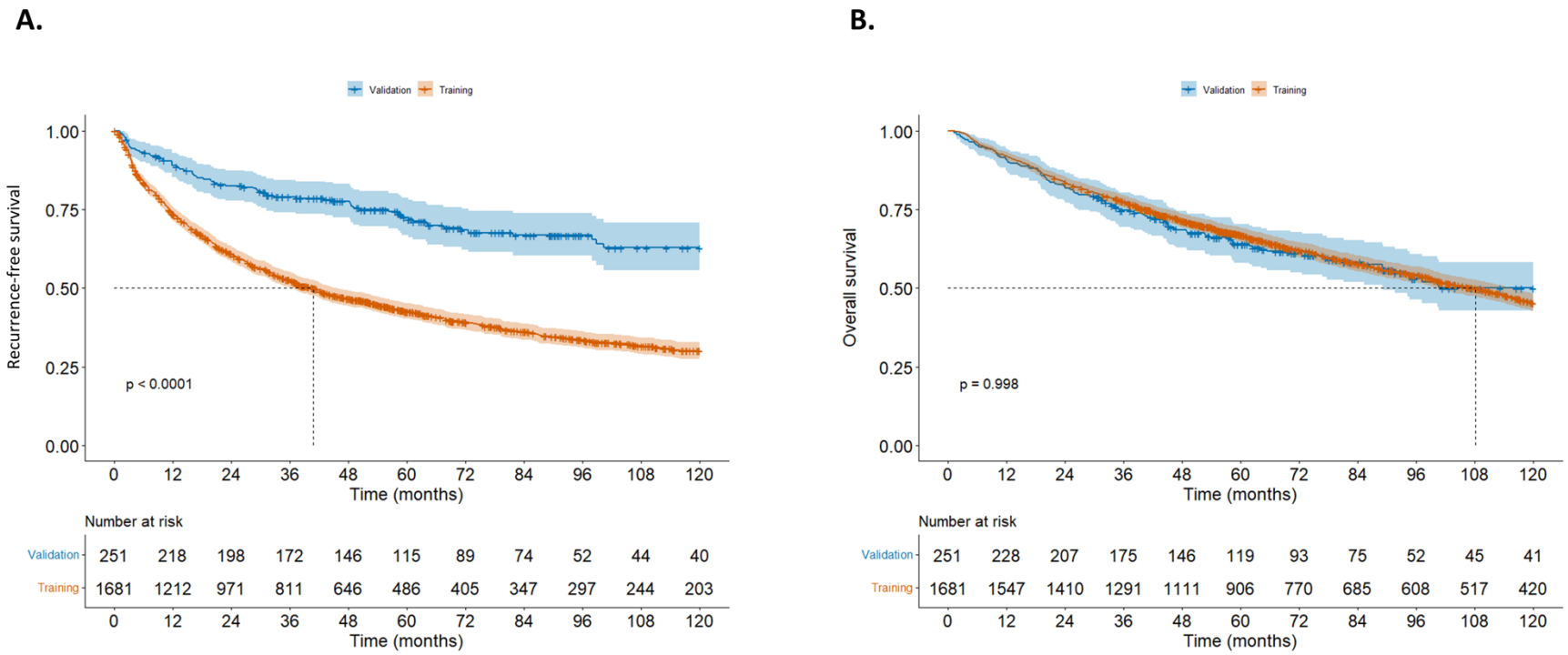
[a]include sorafenib, regorafenib and lenvatinib

[b]include atezolizumab plus bevacizumab, nivolumab and pembrolizumab

[c]include FOLFOX and UFUR

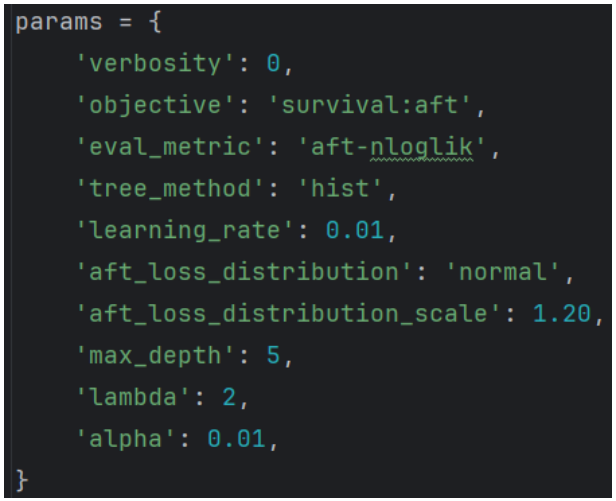
[d]include portal vein embolization and clinical trial

Supplemental Figure 1. Comparison of long-term outcome of HCC patients after hepatectomies in training and validation cohorts.



(A) Long-term recurrence-free survival. Patients in the validation cohort have significantly longer recurrence-free survival compared to the training cohort (p<0.001). As for early recurrence, 643 patients (38.3%) in the training cohort and 44 patients (17.9%) in the validation cohort experienced recurrence within two years after hepatectomies (p<0.001). **(B) Long-term overall survival.** There is no significantly difference in overall survival between training and validation cohort (108.3 months (IQR 100.0-116.0) vs. NA (IQR 89.3-NA); p=1.00).

Supplemental Figure 2. Programmatic hyperparameter configuration registry for the XGBoost-AFT survival analysis framework.



```
params = {
    'verbosity': 0,
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    'eval_metric': 'aft-nloglik',
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    'learning_rate': 0.01,
    'aft_loss_distribution': 'normal',
    'aft_loss_distribution_scale': 1.20,
    'max_depth': 5,
    'lambda': 2,
    'alpha': 0.01,
}
```
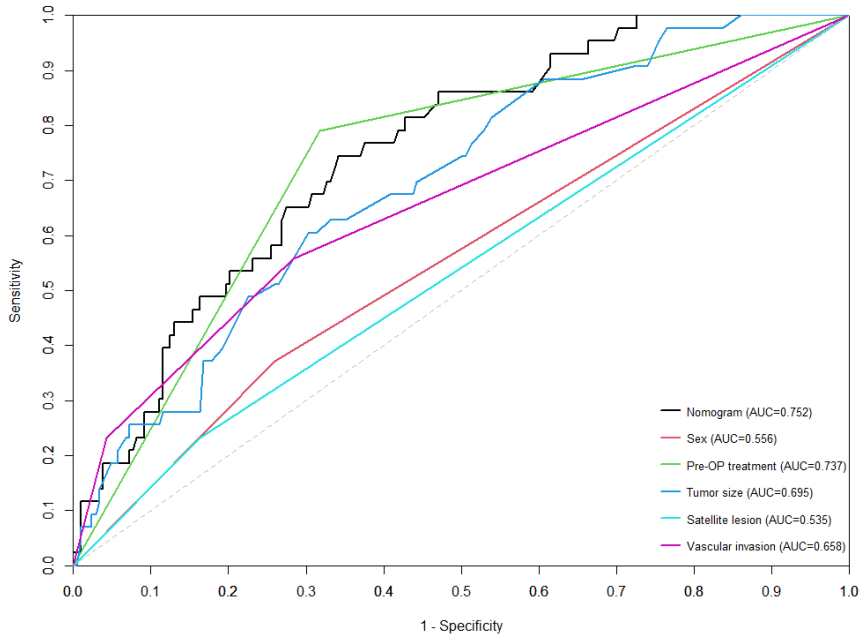

The screenshot illustrates the exact distribution constraints, regularization bounds, and optimization loss parameters utilized during algorithmic training to mitigate overfitting.

Supplemental Figure 3. Time-dependent Receiver Operating Characteristic (ROC) analysis of the final prognostic nomogram within the independent external validation cohort (n=251).



Panels illustrate the model's discriminative performance and respective Area Under the Curve (AUC) metrics for predicting early hepatocellular carcinoma recurrence at 24 months post-hepatectomy.